COLLEGE STUDENTS' GIS SPATIAL CONCEPT KNOWLEDGE ASSESSED BY CONCEPT MAPS

A Dissertation

by

KATSUHIKO ODA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2011

Major Subject: Geography

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Approved by:

Chair of Committee,	Sarah W. Bednarz
Committee Members,	Robert S. Bednarz
	Robert J. Hall
	Andrew G. Klein
Head of Department,	Vatche P. Tchakerian

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ABSTRACT

College Students' GIS Spatial Concept Knowledge Assessed by Concept Maps.

(May 2011)

Katsuhiko Oda, B.A., Nara University;

M.A., The University of Toledo

Chair of Advisory Committee: Dr. Sarah W. Bednarz

The development of spatial thinking proficiency has been increasingly demanded in Geographic Information System (GIS) education. Despite this educational trend, there is little empirical research on college students' spatial concept knowledge, which critically affects the quality of spatial thinking. This study addressed the following three research questions: 1) What differences exist between students' understandings of spatial concepts at the beginning, middle, and end of an introductory-level GIS course?, 2) What spatial misconceptions students may possess while taking an introductory-level GIS course?, and 3) Which spatial concepts are easy or hard for undergraduate students to understand? The researcher asked twelve participants who were taking an introductory-level GIS course to create concept maps about space and revised their concept maps in three experiment sessions. For the first question, the researcher scored the sixty obtained concept maps and statistically analyzed those scores to examine if there is any significant difference among the scores of the three experiment sessions. For the second question, the researcher examined participants' misconceptions by analyzing the incorrect statements of distortion, map projection, and scale. For the third question, the researcher statistically analyzed concept-based scores to examine if there is any significant difference among the scores of three different complexity levels.

A main finding for the first question was that there was a significant difference among the scores of the concept maps created in the first session and the scores of the concept maps revised in the second and third sessions. This implied that participants could successfully revise their own original concept maps in the middle of a semester. The result of the study of the second question indicated that a half of participants misunderstood the concepts of map projections and scale. This result suggested that some undergraduate students may have difficulty shifting from scientifically inappropriate spatial concept knowledge to appropriate knowledge. Analysis of the third question resulted that the concept-based scores of simple spatial concepts are significantly higher than the scores of complicated spatial concepts. This result inferred that participants' scores decreased as the complexity of concepts increased.

DEDICATION

To all the persons I have met so far

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NOMENCLATURE

GIS	Geographic Information System
GPS	Global Positioning System

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CHAPTER I

INTRODUCTION: THE IMPORTANCE OF RESEARCH

Context of Research Problem

The use of computer technology in teaching and learning subjects has been controversial among educators since computers became widely used. Different opinions have been expressed regarding the effects of technology on students' learning (Committee on Developments in the Science of Learning with Additional Material from the Committee on Learning Research and Educational Practice and National Research Council 2000, Guerrero, Walker and Dugdale 2004). Some researchers argue that computer technology improves students' learning. Unlike traditional media, computer technology can be an interactive communication medium that enables students to solve problems independently. Students can learn what they are interested in, explore it more fully, and continuously refine their knowledge. In addition, computer-assisted teaching effectively promotes students' visualization of difficult-to-understand concepts (Committee on Developments in the Science of Learning with Additional Material from the Committee on Learning Research and Educational Practice and National Research Council 2000, Guerrero et al. 2004). On the other hand, opponents point out learning with computer technology tends to be superficial (Barak 2004). In the 1980s and early

This dissertation follows the style of *Annals of the Association of American Geographers.*

1990s, American secondary schools tended to teach students how to use a computer rather than how to apply computers to problem solving (Becker 1993). This inclination to teach technical aspects caused the neglect of the related fundamental concepts that are necessary for problem solving, information retrieval, and critical thinking.

This dispute can be applied to the case of Geographic Information System (GIS) education. GIS is a tool for spatial problem solving and decision making. Even though GIS has the potential to be a useful support system in education (Baker and White 2003, National Research Council 2006, Shin 2006), GIS education tends to teach about GIS rather than with it (Brown et al. 2003). Operating GIS software is complicated for beginners, which inclines them to concentrate on attaining software operation skills. Some novices tend to dismiss attaining knowledge that is necessary for spatial problem solving (National Research Council 2006). Worse yet, some students may complete a GIS course without attaining spatial skills such as the ability to read and interpret maps, to create effective maps, and to create spatial hypotheses (Thompson 1991). Such students can hardly go beyond the default settings of GIS software (Downs 1997). For example, they create choropleth maps with inappropriate data classifications. Although the map does not express a true spatial pattern, they blindly believe the output from the GIS software. In this case the GIS software that should be used for empowering people's spatial thinking is used as a substitution for the act of thinking spatially (Downs 1997).

GIS is supposed to be an effective tool for reinforcing students' spatial thinking competency (Goodchild 2006, Kerski 2008b, National Research Council 2006). Even though conceptual knowledge supports higher-order thinking such as problem solving

(Howard 1987), there is little empirical research on college students' conceptual knowledge in relation to geospatial science. This study examined if university students had developed their own knowledge related to spatial concepts during an introductory-level GIS course and what made students' learning of spatial concepts difficult.

GIS Education

GIS education is a conglomeration of dichotomies which characterize its nature and categorize it into the following four schools: GIS as a collection of marketable skills, GIS as an intellectual theme and new discipline, geography as the home discipline of GIS, and GIS as an enabling technology for science. The first school regards GIS as a collection of tools and methods and emphasizes attaining GIS operational and practical skills. The second school posits GIS itself is a research topic and can be treated as a new discipline, GIS science. The third school advocates geography is the home discipline of GIS because many of the related principles originate from geography. The fourth school values GIS as a tool for analysis and scientific inquiry (Kemp, Goodchild and Dodson 1992). Each of the schools has a different combination of the dichotomies that relate to course content, course delivery means, and course objectives (Table 1). This existence of three dichotomies shapes the multifacetedness of GIS education.

The first dichotomy, course content, is between teaching about GIS and teaching with GIS (Sui 1995). Teaching about GIS emphasizes theoretical and practical knowledge and skills for GIS problem solving. For example, the format of spatial and attribute data and the related data handling are possible topics in this type of teaching.

On the other hand, teaching with GIS emphasizes geographic inquiry processes and the knowledge that can be obtained from inquiry. The development of geographical knowledge and intelligence through analyzing areal differentiations and spatial relationships is a main aim in this type of teaching. College and university-level instruction has focused on teaching about GIS (Goodchild 1985). Introductory-level GIS courses especially tend to spend the most time on teaching about GIS. However, techno-centered content becomes obsolete and does not help students develop geographic knowledge and intelligence. Curriculum that is well balanced between teaching about GIS and with GIS is recommended (Sui 1995).

Table 1. Three dichotomies in GIS four schools

	GIS as a collection of marketable skills	GIS as an intellectual theme and new discipline	Geography as the home discipline of GIS	GIS as enabling technology for science
First Dichotomy	Teaching about GIS			Teaching with GIS
Second Dichotomy	Training	Education	Training and Education	
Third Dichotomy	Professional Development		Professional Development and Citizenship Education	

The second dichotomy, course delivery means, is between lecture and laboratory (DiBiase 1996). A lecture approach educates students about GIS concepts and principles in a linear structured format. The units of curriculum are basically programmed on the basis of theories and concepts. In contrast, a laboratory approach trains students for actual use of geographic information and spatial technologies. Curriculum units are planned on the basis of spatial tasks. The lecture approach deals with one or a few GIS concepts in a single class; as a result, students can surely learn these concepts. On the other hand, a laboratory approach tends to cover several GIS concepts in a single session. Students can select and concentrate on the concepts they find interesting more flexibly than in the lecture approach. As evidence of the advantages and disadvantages in both of approaches, most GIS curricula widely practiced in US higher education institutions adopt a combination of the two delivery styles. However, synchronization of between lecture and laboratory is difficult for instructors to achieve and students may be confused (DiBiase 1996, Kemp et al. 1992).

The third dichotomy, course objectives, is between professional development and citizenship education. In professional development, GIS is regarded as a collection of marketable skills. Students take GIS courses to become GIS experts or proficient GIS users in their own fields. Most college-level GIS courses and GIS software vendors' seminars have this type of objective. The software used is commercially available software tailored for GIS experts. In citizenship education, GIS is regarded as a tool to reinforce spatial thinking proficiency for real-life situations. The ultimate goal is to educate students to become good decision makers that utilize geo-spatial technology wisely (Kerski 2008a). The rationales for GIS in this dichotomy are enhancing spatial thinking skills, offering diverse employment opportunities, and promoting local-community-based learning (Bednarz 2004). Unlike professional development, a target group is people who do not plan on using GIS for their occupations but rather enrich their own lives through the use of spatial technologies. Not only college students and adults but also K-12 students can receive benefits from the latter type of GIS education. The software for this objective should be designed to decrease burdens on users' technical operations. GIS software tailored for general educational use or widely used geo-spatial technologies such as virtual globes and mobile computers with Global Positioning System (GPS) equipped are suited for spatial literacy education (Kerski 2008a).

Since GIS began to be used as a tool in research, GIS education has expanded from limited groups and institutions to diverse disciplines and ages. The expansion is characterized as a move from teaching about GIS for professional development to teaching with GIS for citizenship education. The improvement of real-world GIS data availability, software and hardware usability, and geo-spatial technology accessibility has attracted a wide range of users and provided them with valuable outputs through spatial problem solving. As a consequence, people who have become aware of the benefits of spatial thinking have discussed spatial thinking education since 2000 (Goodchild 2006, Kerski 2008b, National Research Council 2006). GIS education has begun to resonate with the twenty-first century society that faces a variety of unpredictable and complicated issues (Bednarz 2000).

Spatial Thinking

Spatial thinking is a collection of cognitive processes associated with objects and events that exist in a wide range of spatial scales. That range covers from atomic nuclei to galaxy superclusters, which makes spatial thinking usable in a variety of situations and disciplines. Spatial thinking functions for three purposes: a descriptive function that concerns communicating spatial information, an analytic function that concerns grasping spatial layouts and structure, and an inferential function that concerns inferring the future behavior of objects in space. A set of these functions enables people to describe spatial phenomena, analyze them and predict the subsequent phenomena for spatial problem solving (National Research Council 2006). Spatial thinking requires people to use spatial concepts, spatial representations, and spatial reasoning (National Research Council 2006). Each of the three components performs differently cognitively; however, all the elements engage spatial entities such as spatial relationships, coordinates, and geometries.

Concepts refer to objects and events abstracted by mentally generalizing and discriminating instances based on similarity and dissimilarity. Instances categorized into the same concept share common characteristics and attributes. This enables a person to judge if a stimulus is an example of the category or a non-example (Howard 1987). Conceptual knowledge has a hierarchical structure interconnected with superordinate concepts and subordinate concepts. Superordinate concepts are positioned at the high levels of a hierarchical structure and include more general attribute information than subordinate concepts (e.g., an animal can move around by itself). Subordinate concepts are subsumed by superordinate concepts at the low levels. Subordinate concepts inherit the attribute properties from the superordinate concepts (e.g., a bird can move around by itself) and also have original attribute properties (e.g., a bird has wings). As a consequence, subordinate concepts positioned at the lowest level include the least general and the most specific attribute properties among the concepts embedded in a hierarchical structure (e.g., a penguin can move around, has wings, and can swim). This hierarchical structure tends to have taxonomical information (Collins and Quillian 1969).

Spatial representations refer to the way in which a person mentally constructs and organizes spatial information that can be represented in an externalized way or a mentally internalized way (Ness and Farenga 2007). External representations are the products that represent spatial entities mentally interpreted by people. Sketch maps and architect's blueprints are examples of external representations. External representations contain spatial referents and need to be depicted in any media including miniature models and verbal descriptions through the use of non-spatial skills such as drawing skills and language skills (Hart and Moore 1973, Liben 1981). On the other hand, internal representations are mental constructions of spatial entities (Hart and Moore 1973). There are two types of internal representations: spatial thought and spatial storage. Spatial thought is imagery that can be reflected mentally and is consciously accessible for spatial thinking. For example, a mental building layout people intentionally use to move around the building is an example of spatial thought. In contrast, spatial storage is not consciously accessible for people. An individual hypothesizes about a spatial representation without being cognizant; however, a person who observes the individual can recognize that person mentally possesses a spatial representation. For instance, a driver can use an accelerator and a brake without being conscious of those positions. The driver does not intentionally use the representation, though the front seat passenger can observe the driver knows the accelerator and brake positions. Once the driver becomes cognizant of the positions, he or she intentionally accesses the mental representation. Thus, the positional information is no longer spatial storage but rather spatial thought. This characteristic of spatial thought closely relates to individual's performance of some tasks and competence (Liben 1981, Newcombe 1981).

Reasoning is a mental process of obtaining complementary information from the knowledge a person already knows. Four types of reasoning may be identified: clarification, basis, inference, and evaluation (Ennis 1987, Quellmalz 1987). Clarification refers to the way in which individuals analyze arguments and situations and identify problems, hypotheses, and theses. Basis refers to the way in which individuals evaluate the credibility and significance of support, arguments, and findings obtained from other information sources or personal observations. Inference refers to the way in which individuals determine unknown information based on an inductive or deductive approach. Evaluation refers to the way in which individuals judge the adequacy of their own approaches and solutions for problem solving.

Each of the three cognitive components in spatial thinking has unique functions, though the components function interdependently. For example, spatial representations support spatial reasoning. Liben and Downs (1991) examined preschool children's understandings of spatial representations and the performance of reasoning. In interview sessions, subjects were asked to view a black-and-white aerial photograph and interpret geographic features shown in the photograph. Most subjects were able to find buildings, roads, and cars, though they were not able to find grass, trees, and a baseball field. One of subjects was not able to recognize grass on the map because he or she expected the representation of grass would be green but it was not. Some subjects supposed that an upper part of a map represented skies, which hindered them from interpreting geographic features on an aerial photograph. The preschool children who participated in the interview session poorly understood the fact that representations have alternative forms for size, dimensionality, shape, and color, and are not necessarily maintained in the actual representations themselves. They were also asked to plan a route between two places by referring to a map. Most of them had difficulty indicating meaningful routes from one location to the other. Some subjects did not follow streets and showed a straight line between a beginning point and ending point. Although most of the subjects knew that a map was used for route planning, they could not use a map to identify a possible route (Liben and Downs 1991). The results of Liben and Downs' study imply that spatial representations and reasoning function interdependently, and poor spatial representations make reasoning more likely to fail.

Spatial concepts also support the other cognitive aspects of spatial thinking. Battersby, Golledge, and Marsh (2006) examined students' understanding and use of the concept of map overlay. The subjects, middle-school, high-school and undergraduate university students, were asked to solve a spatial problem that required the use of cartographic overlay. The researchers also asked subjects to describe how they solved the problem to check if subjects used the concept correctly. The results showed undergraduates and high-school students outperformed middle-school students in solving the overlay problem. In addition, more undergraduates and high-school students used overlay to solve the problem than middle-school students (Battersby et al. 2006).

This implies that the use of spatial concepts is necessary for higher-order spatial thinking, and poor understandings of concepts degrade the quality of spatial reasoning and the effective use of spatial representations.

Spatial concepts, spatial representations, and spatial reasoning function differently cognitively; however, the three cognitive components do not function independently but rather dependently. What functions of the components are used and how those functions are interrelated vary in the applications of spatial thinking. Considering the versatility of functions and interdependency among the three cognitive components, it can be said that spatial thinking is a multifaceted amalgam of spatial concepts, representations, and reasoning.

Statement of the Problem

Some scholars advocate GIS is an effective education tool for nurturing people's spatial thinking (National Research Council 2006), and spatial thinking education with GIS is necessary (Goodchild 2006, Kerski 2008b, National Research Council 2006). However, it is still unclear whether students develop their own spatial thinking competency through an education in GIS. Even if we can assume that students can develop their own spatial competency by receiving an education in GIS, there is still one concern: how do students develop spatial thinking competency while learning GIS.

When it comes to spatial concepts, which are the basis of spatial thinking (Golledge 2002), the domain of existing research is limited. Some researchers have attempted to establish an ontology of spatial concepts (Agarwal 2005, Golledge 1995, Kuhn 2001, Mark, Smith and Tversky 1999, Smith and Mark 2001, Timpf et al. 1992) and to examine students' spatial concept knowledge (Battersby et al. 2006, Golledge, Marsh and Battersby 2008, Marsh, Golledge and Battersby 2007). Golledge and his students (Battersby et al. 2006, Golledge et al. 2008, Marsh et al. 2007) developed a conceptual framework of spatial ontology based on the complexity of spatial concepts. They applied the framework to examine students' spatial concept knowledge and performance involving some spatial concepts in cross-sectional studies in which a wide range of subjects from K3 to undergraduates participated. However, they did not track the process of conceptual development, identify misunderstandings about spatial concepts, or empirically examine the degree of difficulty of spatial concepts in the case of students who take a college-level GIS course.

The ultimate goal of GIS citizenship education is to educate students to become spatially literate persons (Goodchild 2006, Kerski 2008a), and spatial thinking is also essential for GIS professional development and a first step for attaining GIS skills (DeMers 2009). Even though spatial concepts have a critical role in spatial thinking with GIS, there is little empirical research that focuses on students' developmental process and difficulties in learning spatial concepts. Exploring students' conceptual knowledge related to geospatial science courses may provide a source of valuable information for GIS education to reinforce students' spatial thinking proficiency. This study examined if university students' concept knowledge was improved during an introductory-level GIS course and what difficulties students had in attaining spatial concepts.

Purpose of the Study

The first purpose of this study was to probe the development of spatial concepts in undergraduate students who were taking an introductory-level GIS course. A second purpose was to examine if college students have misconceptions related to GIS spatial concepts. A third purpose was to explore the complexity of spatial concepts in terms of students' comprehension. These three purposes provided evidence used to suggest improvements to GIS education to help students develop spatial concept knowledge more effectively.

Significance of the Study

This study contributes to the development of a theoretical foundation emphasizing spatial literacy for GIS education. Such an education will enable people to describe, analyze, and predict the behavior of spatial phenomena (National Research Council 2006). Spatial literacy is as important as other types of literacy: reading, writing, and arithmetic (Goodchild 2006). It is increasingly important for everyone to be spatially literate; good decision making in daily life relies upon effective spatial thinking. Spatial thinking enables people to grasp physical spatial layouts and structures and abstract relationships (National Research Council 2006). In the case of physical layouts and structures, people recognize building structures by drawing architecture blueprints. In the case of abstract relationships, people comprehend an organism and its ancestors' phenotypes by referring to pedigree charts. According to a survey of employees who received a geography degree and employers in major workforce sectors (Solem, Cheung and Schlemper 2008), 73.1 percent of respondents regarded skills related to spatial literacy as a skill area used frequently in their workplaces while approximately 75 percent regarded skills for communication, writing, critical thinking, and problem solving as necessary general skill areas. Spatial literacy can be regarded as the fourth literacy every student must equip oneself for a job; however, there are very few models of how spatial literacy should be taught in GIS-related disciplines (Goodchild 2006). Considering that spatial literacy is necessary for every student, including non-spatial science majors, enhancing spatial literacy in GIS education is an urgent issue not only within spatial science disciplines but also throughout higher-education institutions.

GIS courses emphasizing spatial literacy would be established on the basis of a well-balanced mixture of geospatial technologies and geospatial concepts (Goodchild 2006). Geospatial concepts are indispensable and fundamental for identifying, describing and analyzing various spatial phenomena that are described in spatial media such as maps or that happen in the real world(National Research Council 2006). For example, people often use a road map to travel to a restaurant they have not visited before. When people speculate about how to go to the restaurant, they associate their location in the real world with its location on a map and plan possible routes to the restaurant. These mental tasks necessitate the use of geospatial concepts such as location, spatial layout, spatial scale, map projections, and coordinate systems (Downs and Liben 1991, Gersmehl and Gersmehl 2007, Uttal 2000). Without these spatial concepts, people would be unable to reach their destination because of map misinterpretation. Students may attain some simple spatial concepts in their daily lives; however, ideally they should learn spatial concepts in a formal setting. Golledge and others (2008, p. 287) stated that "students, teachers, and society in general can benefit from exposure to effectively presented and taught geospatial concepts and by exposure to geospatial technologies." Research on which spatial concepts should be presented and how those concepts should be taught in GIS education is increasingly in demand.

GIS education has the potential to equip students with a degree of spatial literacy useful in their work places and for their everyday lives. GIS education through which students can develop their own spatial concept knowledge should be studied. This study probes students' understandings of spatial concepts, and the results can be utilized to refine a spatial science curriculum and equivalent course materials which promote spatial thinking in the contexts of formal GIS education. Evidence obtained from this empirical study about students' spatial concept knowledge can suggest the optimal and well-balanced use of geospatial technologies and geospatial concepts in GIS education.

Research Questions

The major objective guiding this study was to examine conceptual development experienced by undergraduate students taking an introductory-level GIS course and students' difficulties in comprehending spatial concepts. This study has the three specific research questions:

1. What differences exist between students' understandings of spatial concepts at the beginning, middle, and end of an introductory-level GIS course?

2. What are the geospatial misconceptions students may possess while taking an introductory-level GIS course?
3. Which geospatial concepts are easy or hard for undergraduate university students to understand?

Research Methods

To track and probe individuals' conceptual development and understandings of spatial concepts, this study adopted a single-group time series design as a part of a quasi-experimental design. The researcher conducted experiments in both the 2008 fall semester and the 2009 spring semester. In a set of experiment sessions, undergraduate students enrolled in an introductory-level GIS course participated in a training session to learn how to create a concept map, followed by three experiment sessions in the beginning, middle, and end of each semester. A main activity of the experiment sessions was to construct a spatial concept map. Of seventeen recruited undergraduate students, twelve participants satisfactorily completed the training session and the three experiment sessions.

After obtaining spatial concept maps from the participants, the researcher scored those maps using two scoring schemes. One scheme counted the number of map components to measure the degree to which the structure of a concept map is hierarchically complex. The other scheme scored the correctness of interrelationships between concepts. The concept map scores were then utilized for quantitative analyses to examine students' conceptual development and to identify lower and higher-complexity concepts related to spatial concept learning.

Study Assumptions

This study included the following assumptions:

1. The selected students appropriately attained concept mapping skills before they started the experiment sessions.
2. The selected students appropriately answered the questions that were asked in the experiment sessions.
3. The selected students created concept maps that accurately represented their conceptual knowledge.
4. Subjects' concept mapping appropriately reflected their recall processes.
5. Scoring concept maps appropriately measured the selected students' conceptual knowledge and development properly.
6. The interpretation of the results accurately reflected the selected students' conceptual knowledge and development.

Study Limitations

The study has the following limitations:

1. This study adopted a time series design; each participant received three treatments. Earlier treatment(s) may have an effect on subsequent treatment(s).

2. This study involves a single group of subjects. This hinders the researcher from comparing multiple groups.
3. This study is based on a quasi-experimental design. This disables the researcher to control extraneous variables fully and definitely conclude that a GIS course effects students' conceptual development.
4. Obtained concept maps were scored by a single assessor, which means that inter-rater reliability was not examined.
5. In this study, a small number of subjects participated on a volunteer basis. This implies that the sample may not be representative of undergraduate students who take a GIS course in US universities. Results may not be generalizable.

Considering these limitations, it can be said that the data and results of this study is not confirmatory, but rather suggestive and exploratory.

CHAPTER II

REVIEW OF LITERATURE

Introduction

The central question of this research is to investigate college students' conceptual knowledge development related to spatial thinking. In order to explore the question, this study covers two academic fields: geography and educational psychology. In the discipline of geography, researchers have discussed spatial thinking and spatial concepts as they apply to geography. However, there is little research on the assessment of conceptual knowledge. In contrast, the discipline of educational psychology has little research on spatial thinking and spatial concepts. Instead, this discipline has extensive research on students' conceptual knowledge and related assessment.

This study adopted the concept map as an assessment tool for tracking the development of students' spatial concept knowledge and identifying their difficulties in comprehending spatial concepts. The literature review is divided into four sections to reflect the aims and methodology of the study. The first section reviews the literature on conceptual development. The second section discusses conceptual change. The third section focuses on the concept map as an assessment tool. The fourth section explains spatial concepts that are necessary for the use of GIS and the interpretation of maps. At the end of the literature review, a summary links the four sections.

Conceptual Development

Concepts are the labels of objects or events that are defined by other concepts (Keil 1989, Novak and Gowin 1984) and can be categorized based on common critical attributes among two or more instances (Howard 1987, Smith and Medin 1981). The labeled concepts are denoted by a socially accepted sign or symbols including a word or words. The socially standardized attributes of concepts are usually assigned by experts and authorities and stated in unabridged dictionaries and lexica (Klausmeier 1992). These characteristics enable individuals to mentally distinguish examples from the nonexamples of a category (Klausmeier 1992), utilize concepts for problem solving, and communicate with one another (Ausubel, Novak and Hanesian 1986, Howard 1987, Medin, Lynch and Solomon 2000).

To learn a concept, people abstract some attributes from sensory stimuli such as objects or events and categorize those stimuli into a certain class (Howard 1987). For example, a person notices a plant has double flower and prickles on the stems and categorizes the plant into a class of rose. Two main perspectives on concept formation based on attribute abstraction have been discussed among cognitive psychologists. The first perspective is the classical view; the second one is the prototype view. A prominent assumption of the classical view is that all instances of a single concept have all the attributes that define the concept. A set of defining critical features is necessary for forming a concept. For example, the necessary attributes of a triangle are a closed figure and a three-sided figure. Either of the attributes is not sufficient to define the concept; rather, a condition in which both of the attributes jointly function is sufficient to formulate the rule. This necessary and sufficient condition is a main characteristic of the classical view (Smith and Medin 1981). On the other hand, the prototype view posits that only some of the corresponding defining attributes can become a composition of a single concept (Klausmeier 1992) and formulates the central tendency of the instances' properties or patterns (Rosch 1973). The central tendency (prototype) encompasses distinctiveness and the probability of occurrence for defining attributes. In the case of the concept bird, feather and wing are representative attributes because both of them are distinct and more likely to occur with birds. In contrast, flying and singing are less likely to occur with birds even though those attributes are distinct. As a consequence, people cite robins as an example of the concept bird more frequently than penguins because they usually recall instances that have high distinctiveness and occurrence probability (Smith and Medin 1981).

Concepts people already know help them develop their own conceptual knowledge. According to the prototype view, people can form a prototype by abstracting the characteristics of a single typical instance and refining the attained prototype by identifying the characteristics of two or more instances (Klausmeier 1992, Rosch 1978). For example, a student encounters buffer polygons surrounding geographic line features in GIS buffer analysis. The student may think the concept of buffer is a polygon formed along a line with a certain distance between the polygon boundary and the line. However, his or her initial conception would change as he or she experiences different types of the surrounding geographic features. In his or her final conception of buffer, he or she comes to know that the concept of buffer is a polygon formed around geographic features including points, lines, and polygons. Klausmeier (1992) articulated the process of concept attainment by defining the following four stages: concrete, identity, classificatory, and formal. At the concrete stage, a learner can recognize an item as the same item he or she previously encountered. The context or spatial orientation in which the learner newly encounters an item should be the same as that of the originally encountered item to easily retrieve the corresponding representation from his or her long-term memory. This helps the learner not only discriminate the newly encountered item from its surroundings by paying attention to the attributes of the item but also to refer to the corresponding items registered in his or her long-term memory to decide the new item is the same one as the referenced items. At the identity stage, a learner starts generalizing about an item. The generalization enables him or her to recognize the item even if the perception modality or spatial orientation in which the learner encounters the item is different from that of the initially encountered item. At the classificatory stage, the learner can recognize that two or more different items are equivalent in terms of specific attributes. This allows the learner to almost distinguish examples from nonexamples; however, he or she cannot accurately explain the principles of the categorization at this stage. At the formal stage, the learner finally can perfectly separate examples from nonexamples, state the same definition as experts, and specify critical attributes that help the learner differentiate very similar instances. Thus, the process of concept attainment involves the identification of concept attributes and generalization of the attributes abstracted from multiple instances.

Concept attainment and development affect the cognitive structure of long-term memory that stores conceptual knowledge. The hypothetical representation of cognitive structures is a hierarchical network. The components of the network are a concept node, a labeled link, and a proposition (Figure 1). A concept node, representing a concept, is linked with other concept nodes by labeled links, which creates propositions between and among concepts in the neighbor concept nodes. A proposition encompasses a statement that expresses the attribute of a concept; thus, every concept is defined by a set of other concepts (Shavelson 1974). As people acquire new meaning, new knowledge interacts with previously leaned concepts or propositions (Ausubel et al. 1986). This interaction may modify cognitive structures composed of concepts and propositions (Novak 1998). The degree of structural change can be classified on the basis of the extent to which these hierarchical structures are modified. Ausubel, Novak, and Hanesian (1986) classified conceptual restructuring along a continuum into four categories: subsumption, progressive differentiation, integrative reconciliation, and superordinate learning. In the process of subsumption, which is moderate restructuring, more specific and less inclusive concepts are linked to more general existing concepts in cognitive structures. In contrast, superordinate learning involves radical restructuring of cognitive structures by the modification of inclusive concepts that are located at a higher hierarchical level. Progressive differentiation and integrative reconciliation are in the middle of the continuum between subsumption and superordinate learning. A similar classification scheme distinguishes between accretion, tuning, and restructuring (Rumelhart and Norman 1978). Accretion is the addition of new knowledge to existing knowledge; tuning is the minor modification of existing cognitive structures when new knowledge is incorporated; restructuring is the emergence of a new conceptual framework promoted by incoming new knowledge. As the relationship between subsumption and superordinate learning is moderate restructuring versus radical restructuring, the relationship between accretion and restructuring is also a moderate one versus a radical one. There are some differences between weak and strong restructuring; however, conceptual development results in the modification of cognitive structures. Learners are continuously refining and reorganizing a network of concepts and propositions.

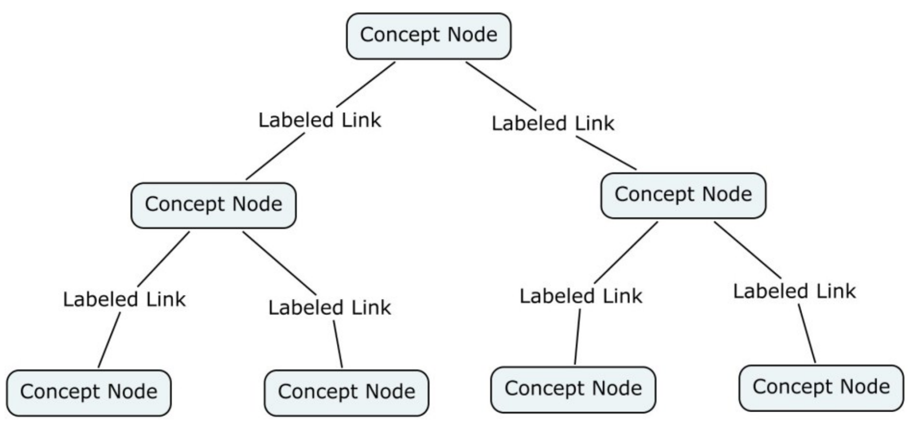

Figure 1. The components of hypothetical cognitive structures

Developed conceptual knowledge networks are structurally and qualitatively different from less developed networks. Champagne, Klopfer, Desena, and Squires (1981) examined students' cognitive representations before and after receiving instruction in geology. The experimenters asked subjects to arrange cards that had geology terms and to explain why they arranged the cards as they had. The experimenters added subjects' comments by drawing lines and labels that indicate interrelationships among the terms. The researchers classified their obtained map-like representations on the basis of structural complexity. The results suggested that students' representation became more hierarchical and congruent with the contents that were covered by instruction. Murphy and Wright (1984) examined differences between experts' and novices' conceptual knowledge structures. Clinical psychology experts and undergraduate novices described the typical characteristics of mentally unstable children on the basis of three diagnostic categories: aggressive, depressive, and disorganized. Specialists of personality and clinical psychology converted the descriptions to attribute lists and analyzed them. The results indicated that experts have a larger number of listed attributes and describe more plausible attributes than novices. Considering the results described above, it can be said that the structure of cognitive representations tend to become more hierarchical and congruent with the attributes experts define in the process of conceptual development (Shavelson 1972).

People form conceptual knowledge by extracting the attributes of concepts from two or more instances. This concept attainment is the result of associating perceived new instances and knowledge registered in people's long-term memory. Sequential conceptual development brings a modification to people's cognitive structures that are composed of concepts, links between concepts, and propositions. Although the degree to which hierarchical knowledge structures are restructured varies, metaphorically expressed as a spectrum between minor restructuring and radical restructuring, people continuously refine and reorganize their cognitive structures. As a consequence, people develop cognitive structures that are hierarchically organized and more congruent with experts' conceptual knowledge.

Conceptual Change

Conceptual change in the field of science has been extensively researched since the latter half of the 1970s (diSessa 2006). The research is premised on the idea that students possess naïve knowledge gained from their everyday experiences. The knowledge is necessary for their formal learning but sometimes hinder students from properly learning some scientific concepts (Vosniadou 1999).

Although researchers agree that naïve experiential knowledge sometimes interferes with formal science learning and disappears as a result of conceptual change, the nature of naïve knowledge is contested. There are two different perspectives on naïve knowledge: the knowledge-as-theory perspective and the knowledge-as-elements perspective (diSessa, Gillespie and Esterly 2004, Ioannides and Vosniadou 2002). According to the knowledge-as-theory perspective, a knowledge structure is highly organized and can be characterized as a hierarchical and coherent network (Özdemir and Clark 2007). The framework of the network structure is relatively wide and partly covers the extent of the corresponding scientifically appropriate theory (diSessa et al. 2004, Özdemir and Clark 2007). This makes students' naïve knowledge have a theory-like character. According to Vosniadou (1994), children's science learning is constrained by the framework. Many children suppose the shape of Earth based on the following two presuppositions: spatial configuration is set upright against a flat ground; and unsupported objects fall downward. The framework that encompasses these two suppositions somewhat matches the extent of the gravity law. However, children who do not understand the law fully tend to think that the shape of Earth is dual Earth, hollow sphere or flattened sphere. The knowledge includes a set of perceptual information, beliefs, presuppositions, and mental representations (Vosniadou 2002). As a consequence of this, students' naïve explanations resemble medieval scientists' explanations (McCloskey and Kaiser 1984). For example, elementary-school children postulate that Earth is a flat or a round disc positioned at the center of the universe, and the sun and the moon move up and down from the horizon. This geocentrism-like knowledge is common among children (Vosniadou 1991). According to Vosniadou (1991), about 85% of her elementary-school subjects consistently utilized their own naïve theories to answer questions about Earth, the sun, and the moon and construct the models of stars and planets. Thus, the knowledge-as-theory perspective posits that theory-like naïve knowledge enables students to predict events and phenomena consistently across multiple domains and contexts. On the other hand, the knowledge-as-elements perspective suggests the structure is loosely composed of relatively isolated primitives. A primitive in a fragmented relational structure activates only the linked primitives when a student recognizes the relevant facts and events (Özdemir and Clark 2007). The activated structure is not large enough to enable students to use the naïve knowledge to predict phenomena consistently. Their explanations and predications change in accordance with domains and contexts. Thus, the characteristic of students' naïve knowledge is highly sensitive to context. This characteristic guides students to have diverse ways of reasoning by referring to the characteristics of contexts (diSessa et al. 2004).

The two types of perspectives also bring two different speculations on the status of conceptual change (Özdemir and Clark 2007). In the case of the knowledge-as-theory perspective, naïve theory will be replaced with scientifically appropriate theory. The highly structured components are dramatically modified in order to incorporate the corresponding normative theory. The conceptual change of the knowledge-as-theory perspective would metaphorically be called revolutionary change; in contrast, the knowledge-as-elements perspectives would metaphorically call conceptual change evolutionary change (Chi and Roscoe 2002, Vosniadou 2007). According to the knowledge-as-elements perspectives, the extent to which conceptual change affects the collection of elements is limited. The structural change is the addition of new elements, the elimination of existing elements, or minor modification of connected elements (diSessa 2002).

Naïve knowledge is sometimes referred to as intuitive knowledge, alternative framework, preconceptions, and misconceptions (Chi 2005, Vosniadou 1991). Of these, the term misconception emphasizes students' misunderstanding of scientific explanations (Vosniadou 1991) and students' knowledge that must be removed (Chi and Roscoe 2002). Misconceptions can be categorized into four groups on the basis of content interpretation. The first interpretation is that a misconception is a miscategorized concept in a hierarchical semantic network. Based on this interpretation, conceptual change is supposed to be the shifting of a concept from one category to another ontologically distinct category. For example, students who think that electricity is stored in a battery may postulate that the concept electricity belongs to the category substances rather than process (Chi and Roscoe 2002). A second interpretation is that a misconception is a scientifically inappropriate knowledge system that is attained from students' perceptual experiences. Based on this interpretation, conceptual change is the shifting from naïve knowledge to scientifically-appropriate knowledge (Vosniadou 2002). For example, children between the ages of four and twelve and college students were asked to predict the position where a ball would land after a passenger dropped it from a moving train. Most four- and five-year-old children expected the ball to fall straight down from the moving train; about half of the ten-, eleven-, and twelve-year-olds had the same prediction as the younger children did. Even one-third of the college students expected that the ball would fall straight down from the train. The wrong expectation came from their perceptual experiences of a ball's downward motion. This preconceived notion prevented children and college students from considering the ball's forward motion (McCloskey and Kaiser 1984). A third interpretation of misconceptions is that they are the results of misinterpretation of concepts. The meanings of concepts as used by experts are sometimes different from those used in everyday life, which makes students mistakenly use experts' concepts in the context of their daily lives. For example, physics terms such as acceleration, momentum, speed, and force are used in everyday life as well. However, the meanings of the terms in physics are different from those used in everyday life (Champagne, Gunstone and Klopfer 1985). A fourth interpretation of misconceptions is that it is a case of ad hoc explanations. The explanations occur due to narrow-scope knowledge structures, which cause the faulty explanations that are effective in only a specific situation. Champagne, Gunstone, and Klopfer (1985) observed some middle-school students' explanation about motion was limited to a specific situation so that their explanation was not applicable for other situations.

Thus four types of misconceptions have been identified: miscategorized concepts, scientifically irrelevant knowledge, misinterpreted concepts, and ad hoc explanations. All of the four types are the result of conflict between knowledge attained in informal everyday life and knowledge learned in formal learning. Knowledge attained from students' informal experiences is somewhat structured. This prevents students from migrating from a naïve framework to a scientific framework to explain and predict scientific phenomena correctly. Therefore, educators have been paying attention to misconceptions that are the core elements of conceptual change. When it comes to the nature of naïve knowledge and the process of conceptual change, educators debate two perspectives: the knowledge-as-theory perspective and the knowledge-as-elements perspective. Although the two perspectives have different speculations on the process of conceptual change, both of them presume that conceptual change is the result of the interaction between students' existing structured knowledge and new knowledge.

The Concept Map

The Concept Map as an Assessment Tool

A concept map is a semantic network form composed of multiple propositions. A proposition is a minimum unit that states the attribute of a concept (Ruiz-Primo, Schultz and Shavelson 1997). Each proposition includes two-concept nodes linked with a labeled link (Novak and Gowin 1984). For example, a proposition that states the concept of biosphere has the two concept nodes of biosphere and life and the following linking words: “mainly concerns.” A combination of the two concept nodes and the linking words describes an attribute of biosphere and states that “biosphere mainly concerns life” (Figure 2). A network composed of propositions is usually a hierarchical structure and describes regularities and facts about a primary concept, which is usually positioned at the apex of a concept map. The concept nodes that link to a primary concept are the first-level concepts that subsume lower-level concepts at the subordinate position. Lower-level concepts inherit the attribute information from their superordinate concepts. For example, a primary concept, Earth, links to first-level concepts: biosphere, atmosphere, lithosphere, hydrosphere, and Solar System. Biosphere, one of the first-level concepts, accompanies the concept node of life in the lower level. The second-level concept also subsumes the concept nodes of animal and plant at its subordinate position. Animal and plant are the least inclusive concepts in the group of biosphere. The two concepts of animal and plant inherit attribute information from their superordinate concepts. These hierarchically arranged concepts describe the concept of Earth (Figure 2).

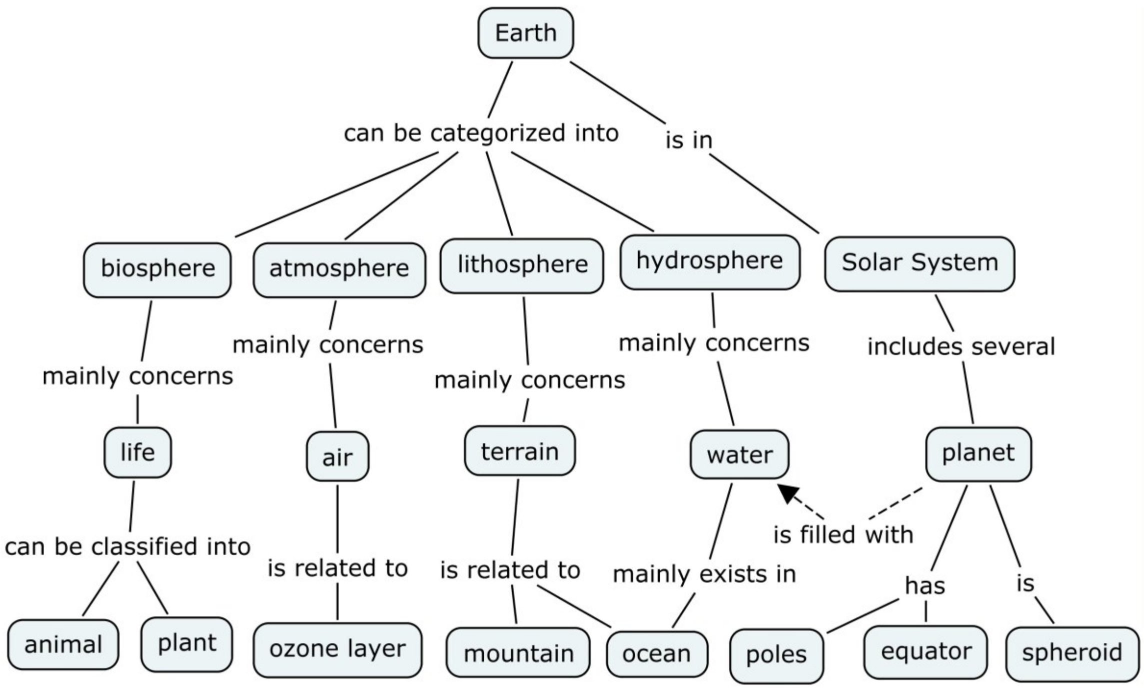

Figure 2. A concept map about Earth

Concept maps elicit subjects' knowledge about relationships among concepts and cognitive structures efficiently. Concept maps composed of multiple propositional statements enable assessors to infer what students know about a primary concept and the related concepts. The interview is supposed to be superior to the concept map for revealing students' understandings in depth (Walshe 2008), though the clinical interview and essay-writing limits subjects to connecting concepts freely because verbal descriptions obtained from these methods are expressed in a linear-fashion. Traditional testing such as true-false or multiple-choice exam also has difficulty assessing how students relate concepts and organize their own knowledge. In consequence, traditional testing requires a considerable number of questions and little metacognitive reflection, and the verbal methods require skilled interviewers and lengthy time (Novak 1998, Rebich and Gautier 2005). Although creating a concept map with high quality necessitates lengthy time for revision (Jonassen, Beissner and Yacci 1993), collecting large numbers of maps in short periods is possible (Walshe 2008). The process of constructing a concept map involves recalling important concepts, contemplating interrelationships among those concepts, positioning those concepts spatially, and explicating the attributes of those concepts (Jonassen et al. 1997). As a consequence, concept maps externalize the important aspects of people's cognitive structures more efficiently and effectively than other traditional methods (Jonassen et al. 1993, Ruiz-Primo and Shavelson 1996, White and Gunstone 1992).

Considering the advantages of the concept map, educators have regarded it as an assessment tool to identify students' current understandings, misunderstandings, and conceptual development. Ruiz-Primo and Shavelson (1996) established a framework for probing the assessment tool aspect of concept maps. They proposed three components: a task, a response formant, and scoring system. Each component has variation, which makes the concept map assessment diverse and flexible for various subject-matter domains. For example, some researchers utilized the concept map to track student's conceptual development and examine their understandings in biology (Barenholz and Tamir 1992, Jegede, Alaiyemola and Okebukola 1990, Martin, Mintzes and Clavijo 2000, Wallace and Mintzes 1990), chemistry (Ross and Munby 1991, Schreiber and Abegg 1991, Wilson 1994), physics (Roth and Roychoudhury 1993), medical science

(Mahler et al. 1991), and statistics (Roberts 1999). Assessment using concept maps has mainly been practiced in the sciences; however, concept maps can also be used in pedagogy (Beyerbach 1988, Lay-Dopyera and Beyerbach 1983) and humanities such as history (Herl and Baker 1996). According Herl and Baker (1996), concept mapping is effective to relate historical facts and events and identify causal associations within and between historical periods.

Concept maps were also used in geography. Walsh (2008) used the concept map as an assessment tool in high-school education for sustainable development. In the lessons, an instructor emphasized interrelationships among the three aspects of sustainability, which are environment, society, and economy. After students created concept maps about sustainable tourism, the researcher analyzed them by counting the frequency of occurrence for categories of sustainability concepts. The results indicated the most occurred three categories were the three aspects of sustainability, which met the contents covered in the lessons. Rebic and Gautier (2005) examined pre- and post concept maps about global climate change. These maps were created by undergraduate students who were taking a geography course. The researchers analyzed propositions described in the concept maps. The results showed the number of concepts and valid propositions and the ratio of propositions to concepts that were occurred in the post concept mapping were larger than those in the pre concept mapping, which means students' understanding on global climate change had been improved. The concepts utilized for mapping in both Walsh's study and Rebic and Gautier's study cover both physical systems and human systems. Interaction between natural environment and human society is one of main topics in geography (Geography Education Standards Project et al. 1994). Concept mapping in geography class enables students to relate physical and human systems and identify facts and events that adhere to interrelationships between the two systems more effectively and efficiently.

Scoring Schemes of the Concept Map

As concept maps externalize the structures composed of concepts and linking words (Novak and Gowin 1984) and the interrelationships among concepts (Ruiz-Primo et al. 1997), concept maps can primarily be assessed by using two types of methods. One method focuses on analyzing the hierarchical structures of the concept maps; the other method examines the quality of the interrelationships among concepts. These two types of methods emphasize different aspects; as a consequence, they bring different outcomes.

A well-known structure scoring method is a scheme proposed by Novak and Gowin (1984). This scoring scheme counts the number of map components including propositions, hierarchy, crosslinks, branchings, and examples (Canas 2003, Novak and Gowin 1984). This scoring scheme and slightly modified versions (Markham, Mintzes and Jones 1994, Stuart 1985) weight map components closely related to hierarchical structures. The assumption of the scoring weight originated from Ausubel’s cognitive learning theory (Ausubel et al. 1986). More general and inclusive concepts subsume a newly attained concept; as a consequence, an inclusive concept that is positioned at a superordinate level has less inclusive and more specific concepts at its subordinate level.

For the Novak and Gowin scoring method, each valid level of hierarchy receives five points; each valid crosslink receives ten points. In contrast, both a valid proposition and an example receive only one point each. A valid crosslink, which links two concepts that are positioned in different branches from one another (See a dashed link arrow in Figure 2), is regarded as a good indicator of integration between newly attained concepts and existing concepts (Novak and Gowin 1984). In short, the structural scoring scheme emphasizes the complexity of hierarchical network forms reflecting well developed mental structures.

The other assessment method focuses on the relational aspects of concept maps. This scoring scheme examines the linguistic structures of propositions and explores the nature of interrelationships among concepts. The fundamental assumption is that a proposition is a minimum unit of the meaning that can be judged in terms of the validity of an interrelationship between two concepts (Ruiz-Primo et al. 1997). A scoring weight for propositional statements is very high as compared with the traditional Novak and Gowin scoring method (Roberts 1999, Rye and Rubba 2002). The quality of interrelationships between concepts is mainly emphasized by weighting the correctness of propositional statements (Rice, Ryan and Samson 1998, Ruiz-Primo et al. 1997). As a consequence, the relational scoring scheme summarizes students' understandings and misunderstandings (Ross and Munby 1991). Thus, the scoring system focusing on the quality of propositions assesses the degree to which students' understanding of concepts meets concepts covered in instruction (Rice et al. 1998, Rye and Rubba 2002).

The relational scoring scheme emphasizes the accuracy of propositions, though there are variations of detail scoring methods. Roberts (1999) modified the conventional scoring scheme by weighting the accuracy of propositions. There are several reasons why this modification occurred. Some concept maps included incorrect propositional links and links with no words. This implies that counting the number of map components would not work sufficiently for incorrect propositions. Moreover, the hierarchy levels of positioned concepts are sometimes ambiguous. For Robert's study, the concepts that can be used in concept mapping were assigned to subjects in advance. This methodological aspect makes counting the number of concepts and proposition less important. Ruiz-Primo, Schultz, and Shavelson (1997) used a square-matrix and a propositional inventory to score their obtained concept maps by focusing on the quality of propositions. The matrix included all possible pairs between concepts; the propositional inventory was used to evaluate the variation in the quality of proposition with five-level scale: valid excellent, valid good, valid poor, don't care and invalid. Rye and Rubba (2002) utilized expert maps in their concept map scoring. They placed a greater weight on concept relationships and propositions than concepts, crosslinks, branching and levels with the concept hierarchy. For the assessment of propositions, they introduced a three-level point criterion based on the degree to which a novice's map and an expert's map matched. The latter two studies adopted master models such as a propositional inventory and an expert map. This enabled the researchers to examine the degree to which students' understandings matched experts' knowledge. This is an advantage of the relational scoring scheme that the structural scoring scheme do not have.

Some of the researchers who have utilized a relational scoring scheme examined its reliability. For example, McClure, Sonak and Suen (1999) compared six concept map scoring methods to identify which one is the most consistent. These six methods include three types of scoring schemes: holistic, relational and structural. Each scheme was scored without a master map and scored with a master map as an evaluation guide. For the holistic, raters judged the map creator's comprehension of the concept by examining the entire map. For the relational, raters examined each proposition and scored from zero to three points by considering the correctness of the proposition. For the structural, raters counted the number of map components such as concepts, propositions and crosslinks. The results of this study suggested the relational with a master map was the most reliable method. One of the possible reasons why the relational is the most reliable is that the method imposes the smallest amount of cognitive load on raters, which enables them to score consistently.

In addition to comparing different scoring schemes, some researchers have examined which criterion should be focused on in the relational scoring scheme. Anderson and Huang (1989) examined whether a relational scoring scheme with an expert map is a feasible measurement for knowledge attained by reading texts. They asked subjects to create a concept map by using concepts and linking words provided in the experiment. The authors scored these concept maps with the following three points: 1) pairs of concepts, 2) the linkage that was used to label the relationship and 3) the direction in which the arrow pointed. The obtained scores suggested that scores focused on propositional quality are more sensitive to assess knowledge growth than scores obtained by a conventional short answer test. In addition, the results showed that the obtained concept map scores highly correlated with standardized measures. Rice, Ryan, and Samson (1998) compared three types of proposition-based scoring methods. These three types have the following different scoring criteria: 1) whether a pertinent concept exists, 2) whether a correct relationship between pertinent concepts exists and 3) whether an incorrect relationship exists. The authors concluded that the second criterion is the most useful as a class assessment because the scores obtained with the criteria correlated with scores on related multiple choice tests.

As evidence of the fact that the two types of concept map scoring schemes have different aspects from each other, correlations between concept map scores obtained by the structural scoring scheme and scores obtained by conventional course performance measures are relatively lower than that between concept map scores obtained with the relational scoring scheme and conventional measurement scores (Rice et al. 1998, Rye and Rubba 2002). The scoring scheme focusing on the quality of propositions assesses the degree to which students' understanding of concepts meets concepts covered in instruction (Rice et al. 1998, Rye and Rubba 2002). In contrast, the scoring system focusing on the hierarchical structure of concept maps assesses the degree to which students' mental structures are complex (Novak and Gowin 1984). The widely-used Novak and Gowin scoring scheme mainly emphasizes the hierarchy of maps mainly. Although the structural scoring scheme may successfully examine how much students integrate new knowledge into their existing knowledge (Ausubel et al. 1986), it may unsatisfactorily analyze how much students understand conceptual knowledge by receiving instruction and improve their own knowledge. Multiple scoring schemes enable raters to assess multiple different aspects of students' conceptual knowledge (Rice et al. 1998). To assess students' conceptual development in a holistic and qualitative way, both of the scoring schemes can be used in the assessment of concept maps.

Since Novak devised the concept map (Novak and Gowin 1984), educators have used it to identify students' current understandings, misconceptions, and knowledge development especially in sciences (Barenholz and Tamir 1992, Jegede et al. 1990, Mahler et al. 1991, Martin et al. 2000, Roberts 1999, Ross and Munby 1991, Roth and Roychoudhury 1993, Schreiber and Abegg 1991, Wallace and Mintzes 1990, Wilson 1994). Although some researchers reported the use of concept maps in geography (Rebich and Gautier 2005, Walshe 2008), there is no case study in spatial concepts that are extensively used in GIS courses. In this study, the researcher asked undergraduate students who were taking an introductory-level GIS course and analyzed their concept maps by adopting the two scoring schemes: the structural and the relational. The utilization of these two schemes enabled the researcher to analyze his obtained concept maps in a more holistic and qualitative way than the use of a single scoring scheme.

Geospatial Concepts

Spatial concepts are one of the elements of along with spatial representations and spatial reasoning. When spatial thinking occurs, spatial concepts support the other two elements by functioning as a framework for identifying, describing and analyzing various spatial events and objects (National Research Council 2006). This characteristic enables spatial thinking is usable in various situations, contexts, and disciplines. For example, mathematics requires some spatial concepts to use diagrams and charts. Those spatial concepts are symmetry, angle, parallel, and so on.

When it comes to GIS software and map use, spatial concepts, which are also called geospatial concepts (Golledge et al., 2008), are indispensable. Converting information obtained from maps to conceptual information requires extensive use of a variety of geospatial concepts. This affects the quality of map use and interpretation (Kaufman 2004, Liben and Downs 1991). Therefore, some researchers have focused on geospatial concepts to examine the quality of people's map interpretation and geospatial thinking. For example, Downs and Liben (1991) focused on map projections and coordinate systems because they hypothesized that a combination of projections and coordinate system functions provide a linkage between maps and the real world for map interpretation. Uttal (2000) dealt with the concept of spatial relations because it helps people think of directions among multiple locations and to gain the information of spatial layout. Gersmehl and Gersmehl (2007) emphasized the concept of location because it is the simplest and fundamental concept that enables people to perform various modes of spatial thinking.

Geospatial concepts support a variety of map use. Spatial acquisition through geospatial media can be classified into the following four modes: use of encoded miniature models, spatial relationship representations, geometric calculation, and spatial inference. In each mode, people use specific geospatial concepts (Table 2). First, maps can be characterized as encoded miniature models. For map construction, scaling and encoding actual geographic features are inevitable. Map users obtain spatial information from encoded miniature models with a bird's-eye view (Liben and Downs 1991). For example, maps require their users to think of which area is drawn at which scale to connect actual locations with the corresponding locations on maps. When map users read another map with different area extent and scale, they may notice the existence of distortion and difference in projection. In this spatial acquisition mode, map readers utilize the following concepts: scale, projection, and distortion. For spatial relationship representations, people can more effectively learn spatial relations with maps than with navigation (Uttal 2000). In a navigational survey mode, people perceive and encode an individual geographic feature such as a landmark and manipulate their obtained spatial information to construct spatial layouts. In contrast, in a map survey mode, they interpret and grasp relations between features in a single glance. Thus, people can acquire and describe spatial patterns and layouts effectively and precisely with maps. In this mode, map users refer to the following concepts: spatial relationship, linkage, pattern, dispersion, and network. For geometric calculation, people can measure area, shape, direction, and distance on maps. Since Ptolemy and his maps adopted a set of longitudinal and latitudinal lines, the geographic map has retained a position of mathematically consistent models (Crosby 1997). Map readers obtain measurements by exploiting the mathematical characteristic. In this type of mode, people use the concepts of area, angle, density, direction, distance, and shape. Some spatial information however is neither shown on a map nor abstracted by geometric manipulation. In order to obtain hidden geospatial information, people must perform spatial inference. For example, map readers can identify a new polygon by overlaying multiple layers. If map readers set a buffer zone with a certain distance from a point, line, or polygon, they can identify a new area. This spatial acquisition mode relies heavily on logical inference (Liben and Downs 1991), which enables map readers to identify the geographic features and information that are not explicitly shown on a map. Overlay, buffer, and association belong to this acquisition mode.

Table 2. Spatial acquisition modes and the related geospatial concepts

Mode	Spatial Acquisition	Examples of Geospatial Concepts
Use of Encoded Miniature Models	Acquisition from encoded miniature models with a bird's-eye view	Distortion, Scale, Projection
Spatial Relationship Representations	Acquisition about spatial relationships through indirect experience	Dispersion, Linkage, Network, Pattern, Spatial Relationship
Geometric Manipulation	Measurements acquisition through geometric calculation	Area, Angle, Density, Direction, Distance, Shape
Spatial Inference	Acquisition of hidden geographic information through spatial inference	Association, Buffer, Overlay

A collection of geospatial concepts can ontologically be categorized on the basis of conceptual complexity. Some geospatial concepts are simple enough to understand and work with and prerequisites for more complicated concepts. For example, the concept of location is simple for people to utilize without understanding more complex concepts such as distance, direction, and proximity (Gersmehl and Gersmehl 2007). Some researchers have discussed simple geospatial concepts and the more complicated concepts that can be derived from the simple concepts. Nystuen (1968) introduced a basis that provides a minimum set of concepts necessary for geospatial analysis. The basis was defined as a collection of independent concepts useable for at least one type of spatial analysis, capable of describing spatial aspects through spatial reasoning. The basis includes direction, distance, and connectiveness. Papageorgiou (1969) reconsidered Nystuen's basis by emphasizing mathematically logical structure of spatial system and regarded the basis as a collection of primitives. The collection incorporated point and time as new primitives because both of them are the concepts that cannot be derived from the other primitives. After Nystuen and Papageorgiou introduced nondivisible geospatial concepts for geospatial analysis, some researchers investigated geospatial primitives and derived concepts. Kaufman (2004) identified the simple geospatial concepts that assist prospective teachers' spatial analysis. The geospatial concepts were identified from observable and measurable spatial relationships. The existence of a single box accompanies the concepts of containment, shape, size and place; a spatial relationship between multiple boxes involves the concepts of distance, direction, connectivity, and pattern. Golledge and his students (Golledge et al. 2008, Golledge 1995, Marsh et al. 2007) established a geospatial concept lexicon and ontology based upon the complexity of geospatial concepts. Golledge reconsidered the primitives introduced by Nystuen and Papageorgiou and suggested a modification following these three points: 1) distance is not a primitive but rather a derivative, because distance can be derived from a set of multiple points; 2) the term point should be replaced with the term location; and 3) location, magnitude, and space-time should be added to the list of primitives because these are necessary to describe spatial systems. Thus, Golledge maintains and provides the foundation for a framework of spatial concepts (Table 3). Identity, location, magnitude, and space-time are primitives. The primitives are fundamental concepts from which further concepts can be derived. Golledge developed five level classification system based on conceptual complexity. The first-order derivatives, which are the simplest derivatives, include arrangements, distribution, direction, distance, and shape. The second-order derivatives feature adjacency, angle, coordinate, and polygon. Buffer, connectivity, gradient, profile, representation, and scale are examples of third-order derivatives. The fourth-order derivatives are the most complex terms such as interpolation, map projection, and subjective space.

Table 3. Golledge's geospatial primitives and derivatives

Concept Levels	Concepts
I Primitive	Identity location, Magnitude, Space-time
II Simple (first-order derivatives)	Arrangement, Boundary, Class/group, Direction, Distance, Distribution, Edge, Line, Order/sequence, Proximity, Shape
III Difficult (second-order derivatives)	Adjacency, Angle, Area, Center, Change, Classification, Cluster, Coordinate, Grid, Growth, Isolated, Linked, Polygon, Spread
IV Complicated (third-order derivatives)	Buffer, Connectivity, Corridor, Gradient, Profile, Representation, Scale, Surface
V Complex (fourth-order derivatives)	Activity space, Areal association, Central place, Distortion, Enclave, Great circle, Interpolation, Projection, Social area, Subjective space, Virtual reality

The foundation laid by Nystuen, Papageorgiou, Kaufman, and Golledge implies that students must learn simple geospatial concepts before they attain more complicated concepts because complex concepts are constructed from the combinations of multiple lower-level concepts. For example, learning the concept of buffer requires students to understand in advance some simpler concepts such as shape, distance, and proximity. This implication would be useful if the assumption of ontology based on conceptual complexity is proved. Research focused on hierarchical relationships in geospatial concept lexica is scarce. This study examines which geospatial concepts are easy or hard for students to learn.

Wrap-up

To use of GIS software and maps, geospatial concepts support several types of mental activities including aerial perception, spatial relationship representations, geometric manipulation, and spatial reasoning. This wide range of usability makes geospatial concepts diverse. Some geospatial concepts are merely simple and primitive; some concepts are derivatives that stem from primitives. In terms of visibility, some concepts can easily be perceived; some concepts can be identified only through internal representations. Moreover, some concepts have semantic gaps between experts' definitions and non-experts' definitions.

The diversity of geospatial concepts enriches outcomes through GIS and map use, though this diversity may be confusing for students trying to understand and apply spatial concepts. This problem prevents students from developing conceptual knowledge and using concepts properly. If a student thinks buffer polygons can be created only from points, he or she might have difficulty learning the concept buffer and creating buffer polygons from the other types of shapes. Although naïve knowledge attained from perceptual experience is helpful for students' concept attainment, misconceptions should be identified and eliminated for further appropriate conceptual development.

Students can achieve concept attainment by identifying common attributes from examples and dissimilar attributes from nonexamples and generalizing those attributes. This concept attainment enables students to further develop their cognitive networks, which are the hypothetical representations of cognitive structures. If students develop their own conceptual knowledge, their cognitive networks will have hierarchical structures and valid interrelationships among concept nodes. There are some different perspectives on concept attainment and development; however, there is also a consensus on concept learning. The consensus is that concept learning is based on intellectual interaction between existing knowledge and new knowledge, and conceptual change is one of the results from concept learning.

There are three assumptions about developed conceptual knowledge: 1) the hypothetical representation of conceptual knowledge is a network form composed of concept nodes and links connecting concept nodes; 2) a developed cognitive structure is hierarchically organized; 3) a developed cognitive structure has the valid explanations of concept attributes. Based on these assumptions, this study examined geospatial concept knowledge brought by undergraduate students who were taking an introductory-level GIS course. The concept map was used in the methodology of this study. The assessment of concept maps had two different scoring schemes: the structural and the relational. The structural explored the complexity of map structures, which examined the degree to which concept maps are hierarchically structured. The relational explored the quality of interrelationships among concepts, which examined the degree to which students understand geospatial concepts covered in instruction. This study used both the scoring schemes to probe students' conceptual development and conceptual change in a holistic way.

CHAPTER III

RESEARCH METHODOLOGY

Introduction

This chapter describes the research methodology that mainly adopted the concept map as an assessment tool. This chapter can be classified into three parts: 1) the context of experiment, 2) the format and contents of experiment, and 3) data analysis. The first part of this chapter discusses why this study was conducted and its background. The second part articulates how the training session of concept mapping and three experiment sessions were conducted. The third part describes how the researcher analyzed the data that were extracted from obtained concept maps.

Purpose of the Study

This study examined if university students had developed their own knowledge related to geospatial concepts during an introductory-level GIS course and what made students' learning of geospatial concepts difficult. The purpose of this study was threefold. The first purpose was to gain an understanding of the development of students' spatial concepts; the second one was to gain knowledge about students' misunderstandings of spatial concepts; the third one was to examine which spatial concepts are easy and difficult for students to attain. In order to achieve these purposes, the researcher examined participants' concept maps and performance of spatial tasks which were obtained from three-repeated measures.

Genesis of the Study

This study focused on college students' conceptual knowledge learning. This theme brought two concerns into the study: 1) whether college students can improve their own conceptual knowledge about spatial thinking while taking a GIS course; and 2) what problems they may encounter during attaining geospatial concept knowledge. These concerns originated from the researcher's experiences as a GIS lab instructor.

The first concern encompasses the development of students' conceptual knowledge related to spatial thinking. The researcher noticed some students were overwhelmed by a series of GIS operations; as a consequence, they dismissed spatial thinking while they were operating GIS software. Although GIS is a tool for spatial problem solving and decision making, they were inclined to follow a GIS manual without thinking of what questions might be possible, why a step of an operation was necessary, and what outcomes were available. Even if they successfully obtained full credit for a GIS lab assignment, they would neglect the related fundamental concepts that are necessary for spatial problem solving, information retrieval, and critical thinking. As some people blindly trust outcomes brought about by calculators, some students were more likely to believe outputs brought about by GIS software without assessing them critically. Ironically, GIS software as a tool for assisting users' spatial thinking tends to become a substitution for the act of thinking spatially. This paradoxical phenomenon concerned the researcher regarding the development of students' conceptual knowledge for spatial thinking in a college GIS course.

The second concern reflects the difficulty of attaining spatial concept knowledge. The researcher noticed there were some complicated geospatial concepts that hindered students from learning about and with GIS. In the first three weeks of the GIS lab, students basically did not have problems completing assignments that focused on basic software operations. However, some students began to falter in their progress after those weeks. The fourth week of the lab mainly dealt with the concepts and skills related to map projection and coordinates. Some students seemed to have difficulty understanding the concepts and attaining the related skills. Knowing what concepts are more likely to confuse students is beneficial for both GIS instructors and students because well-informed instructors would be able to assist students learn those concepts in an effective way.

This study dealt with the two concerns by utilizing the concept map as a tool for revealing students' conceptual knowledge. The results obtained from this study may be useful to develop a curriculum that enhances the development of students' geospatial concept knowledge.

Domain

This study focused on two introductory-level GIS courses offered at Texas A&M University in the 2008 fall semester and the 2009 spring semester. The two courses were "GEOG 390 Principles of GIS" and "FRSC 461 GIS for Resource Management." GEOG 390 was an undergraduate course of the Department of Geography; FRSC 461 was an undergraduate course of the Department of Ecosystem Science and Management. The researcher observed the lectures and laboratories of the two GIS courses in the 2008 fall semester to investigate when students learn specific GIS topics in lectures and when they perform various GIS activities in laboratories.

The content of the lectures of the two courses (Table 4) were both similar and dissimilar. The lectures in GEOG 390 were as follows: 1) the basics of GIS were taught in the first week; 2) coordinate systems and projections were taught in the next three weeks; 3) GIS map data and attribute data were taught in the next three weeks; 4) GIS analysis and interpolation were mainly taught in the next six weeks. The lectures in FRSC 461 were as follows: 1) the basics of GIS were taught in the first two weeks; 2) coordinate systems and projections were taught in the next two weeks; 3) GIS map data and attribute data were taught in the next four weeks; 4) GIS analysis, GPS, and remote sensing were mainly taught in the next five weeks. Both courses dealt with the same topics in the first half of the semester and spatial analysis in the latter half of the semester. The lecture topics that were taught, especially in the latter half of the semester varied. The GEOG 390 lectures tended to contemplate what GIS concepts strongly related to GIS principles. For example, the topic of interpolation required students to understand the concept of autocorrelation that originates from Tobler's First Law of Geography. The FRSC 461 lectures tended to focus on what environmental scientists can do with GIS and spatial technology, such as, GIS analyses utilizing a combination of GIS, GPS, and remote sensing enabling students to make informed resource management decision.

Table 4. The lecture topics of two introductory-level GIS courses

Week	GEOG 390	FRSC 461
1	GIS components, Data dimensionality, Measurements	GIS definition, Spatial factors, GIS applications
2	Map design principles, Map scale, Coordinate system, Projection	Components of GIS, Spatial data, Attribute data, Cartographic model
3	Thematic map, Geoid, Ellipsoids, Datum	Datum, Projection, Coordinate system
4	Projection, Datum, Coordinate system	Projection, Coordinates, Datum
5	Map data entry	ArcGIS file type, Enterprise GIS
6	GIS data structure, Topology	Data sources, Data standards, GIS operations
7	GIS data types, Database management system	Metadata, Database management system
8	Spatial analysis, Overlay, Boolean, Buffer,	Grids, DEMs, TINs
9	Continuous data, Raster	GPS
10	Raster, Interpolation	Remote sensing, Raster analysis
11	Interpolation	Remote sensing, Raster analysis
12	Raster analysis, Terrain analysis	Remote sensing, Raster analysis
13	Raster modeling	GPS Activity

Note: The shaded cells represent different lecture topics between the two courses.

The laboratory component of the two courses (Table 5) also had similarities and dissimilarities. The content and organization of the two laboratories were very similar. Both of them dealt with the basic functions of GIS software, GIS data management, projection and coordinate system settings, and cartographic fundamentals in the first half of the semester. In the latter half of the semester, both courses emphasized spatial analysis. The configuration of the two laboratories was quite different. In GEOG 390, each laboratory session had a focus topic and a mini project that focused on the corresponding focus topic. In each mini project, students were supposed to be a GIS analyst employed at a geomatics company and required to apply the knowledge and skills of the focus topic. The laboratories required students to complete each mini project within one week and take a final lab exam, which tested students' operational skills and ability to apply the skills in different contexts. In the case of FRSC 461, the laboratory had a final project. This project required students to select a project topic with his or her partner by the fifth week of the course and spend considerable time to complete it. In the final project, students were supposed to be employees in an environmental consulting firm and required to solve an environmental question that did not have an absolute right or wrong answer. In the last session of the laboratory, students delivered presentations about their own final projects.

Although both GEOG390 and FRSC 461 were introductory-level GIS courses, these courses were different from one another in terms of philosophy. GIS education can be categorized into the following four schools: GIS as a collection of marketable skills, GIS as an intellectual theme and new discipline, geography as the home discipline of GIS, and GIS as an enabling technology for science (Kemp et al. 1992). These two courses were intended for different schools. The fundamental stand of GEOG 390 was geography as the home discipline of GIS. The lectures and laboratory sessions of this course encouraged students to consider and understand the principles that exist behind knowledge and skills related to GIS. On the other hand, the fundamental stand of FRSC 461 was GIS as an enabling technology for science. This course emphasized scientific inquiry and application in resource management through lectures about geospatial tools and the final project that involved problem solving.

Table 5. The lab activities of two introductory-level GIS courses

Week	GEOG 390	FRSC 461
1	Become familiar with ArcGIS	Become familiar with ArcGIS
2	Become familiar with ArcMap	Become familiar with ArcGIS
3	Create thematic maps and layout hard copy maps	Manage projections and coordinate systems
4	Manage projections, coordinate systems and metadata	Download online raster and vector GIS data and manage meta data
5	Set georeferences	Work with attribute tables and create maps
6	Work with attribute tables and queries	Work with georeferencing, buffering and interpolation
7	Work with spatial queries and spatial joins	Layout hard copy maps
8	Work with map overlay and spatial query	Perform spatial analysis
9	Edit GIS map data	Perform attribute query and attribute table processing
10	Work with interpolation and geostatistics	Perform digitization, interpolation and spatial analysis
11	Perform raster analysis	Final Project
12	Perform raster analysis	Final Project
13	Final lab exam	Final Project

Although the two courses varied in philosophy, there was a common tendency in terms of GIS topic arrangements in the lectures and laboratory sessions. Both courses focused on GIS basic skills and knowledge and the cartographic aspects of GIS in the first half of the semester. GIS basics and cartography skills and knowledge are necessary to acquire spatial information through geospatial media and abstracting measurements from spatial models. These focus topics involve geospatial concepts necessary for map interpretation and manipulation, for example, concepts such as are scale, projection, coordinates, distortion, point, line, polygon, size, shape, and distance. In the latter half of the semester, both courses gradually moved to topics about GIS analysis. GIS analysis relies extensively on understanding spatial relations and inferring spatial information, which also necessitated acquiring and applying geospatial concepts, such as spatial relationship, linkage, pattern, dispersion, network, overlay, buffer, and association.

Experimental Design

The methodology was based on a single-group time series design. Each subject attended a training session and three experiment sessions during a single semester in which he or she enrolled in either GEOG390 or FRSC 461. All of the participants learned how to create a concept map using concept mapping software before they started the first experiment session. The three experiment sessions took place in the beginning, middle, and end of the semester. Participants attended these three sessions in the researcher's office that secured participants' privacy. The duration of these session were approximately one hour. In the first experiment session, participants created a concept map about space and performed tasks that demonstrated spatial skills. In the second session, they created a spatial concept map and revised the concept map they created in the first session. In the third session, they created a spatial concept map, revised the concept map created in the second session, and performed spatial tasks that were similar to the tasks they took in the first experiment session.

Participants

This study involved two introductory-level GIS courses offered at Texas A&M University. The one course was "GEOG 390 Principles of GIS," which was offered by the Department of Geography. The other one was “FRSC 461 GIS for Resource Management” offered by the Department of Ecosystem Science and Management. These two courses were offered in both the 2008 fall semester and the 2009 spring semester. In the two semesters, the researcher recruited seventeen undergraduate students from the two GIS courses (Table 6). Each participant received monetary compensation for each session. Of the seventeen participants, four withdrew from the study. In addition, a set of concept maps drawn by a single participant was hierarchically structured. Although this participant created hierarchical concept maps in a training session, this person created concept maps about space by connecting concepts in linear sequence. As a result, the researcher analyzed data provided by twelve participants. Of the twelve participants, seven participants were students who taking GEOG 390, the other five participants were students taking FRSC 461.

Table 6. The number of participants in this study

Semesters	2008 Fall		2009 Spring		Total
GIS Courses	GEOG	FRSC	GEOG	FRSC	
Number of Original Participants	4	6	3	4	17
Number of Withdrawal Participants	0	3	0	1	4
Number of Complete Participants	4	3	3	3	13
Number of Analyzed Participants	4	2	3	3	12

Instrumentation

Spatial Skills Test

The researcher utilized a part of the Spatial Skills Test (Lee and Bednarz 2009, Lee 2006) in the experiment for this study. The contents of the test were based on the elements of spatial relations defined by Golledge and Stimson (1997) to assess college students' spatial thinking ability. This test involved the following spatial representations and reasoning: 1) performing an overlay operation; 2) converting two-dimensional images to three-dimensional images; 3) synthesizing multiple and different types of spatial information; 4) identifying spatial correlation; 5) performing interpolation; and 6) identifying different types of spatial features. Considering the duration of the experiment sessions, the researcher selected two question items from the test. Both of the selected items involved the spatial concepts used in the experiment sessions and required situational problem-solving. One question item asked subjects to identify the most appropriate location for a new building by overlaying multiple geographic layers; the other question asked them to identify a specific location on the Nile by synthesizing multiple different geospatial information sources including a grid map, a topographic profile, and a narrative. The selected items are shown in Appendix A.

Training of Concept Mapping

In this study, all participants completed a training session about concept mapping. Participants took this session in either the researcher's office or a university computer center. The duration of the session was roughly fifty minutes. The goal of this training session was to learn about concept maps and how to create a map by using concept mapping software. The adopted contents and activities basically followed strategies introduced by Novak and Gowin (1984). During this session, each participant individually followed slides (Appendix D) by themselves.

The session had two parts. Each part included the facts and ideas participants must know and some activities related to concept mapping. In the first part, participants learned the nature, roles, and elements of a concept map. The contents were as follows: 1) what a concept map is; 2) what a concept is; 3) what a proposition is; and 4) what a proper noun is not a concept. In this part, participants were asked to think of the concepts of dog and car and to create a proposition using two concepts. In the second part, participants created two concept maps. For the first map, they created an Earth concept map that was composed of eighteen concepts by following step-by-step instructions. The instructions asked participants to pay attention to the following mapping techniques: 1) to classify concepts into the most inclusive, intermediate, and the least inclusive concepts, 2) to arrange concept nodes hierarchically, 3) to use appropriate linking words, and 4) to think of possible crosslinks and add them. After participants completed the first concept map, they were asked to create a concept map about water by arranging eighteen concepts. Participants were able to create the second map as long as they followed the same steps as in the first map; however, they were asked to create the second map without any instruction. At the end of the second mapping activity, participants were asked to look at their own completed maps again to think of possible parts to be improved and given opportunity to revise them.

The researcher collected all the participants' maps about water and examined them to verify if they had properly created concept maps. As a consequence, the researcher confirmed all participants had appropriately attained concept mapping knowledge and skills.

Concept Mapping

In each experiment session, each participant created a concept map about space by using concept mapping software, CmapTools (Canas et al. 2004). Concept mapping using software has an advantage. Software users can arrange concept nodes and add label links in an intuitive and flexible way. When participants opened the concept mapping window to begin work, they already had thirty spatial concepts provided by the researcher. This setting was consistent in all the three sessions. In their concept mapping, participants were not required to use all thirty concepts; thus, they were able to use only those they were most familiar with. In addition, the researcher advised participants in the concept mapping to create a hierarchical form and to examine their finished map to see if any part needed to be revised. The researcher recorded their concept map construction processes by using computer screen recorder software. After participants completed concept mapping, the researcher asked them to answer two Likert-scale questions that were accompanied by the following statements: 1) I constructed the map without uncertainty; 2) I understand spatial concepts sufficiently to use GIS software. These questions addressed the degree of uncertainty on concept mapping and the understating of spatial concepts. In the second and third experiment sessions, each subject also revised the concept map he or she created in the previous experiment session. After this revision, the researcher asked participants to answer a Likert-scale question with the following statement: the concept map I created in the previous session has been improved.

The researcher and a professor who specializes in GIS selected geospatial concepts to be used in the three experiment sessions. There were two rationales for the concept selection. The first one was that adopted geospatial concepts should be covered in introductory-level GIS courses. The second one was the concept collection should engage a diversity of mental activities: aerial perception, spatial relationship representations, geometric manipulation, and spatial reasoning. The concepts were as follows: location, point, arrangements, distribution, line, shape, boundary, distance, size, spatial relationship, linkage, two dimensions, three dimensions, coordinate, polygon, cluster, dispersion, direction, density, topology, proximity, pattern, buffer, scale, distortion, association, map projection, network, diffusion, and overlay.

Scoring System

The researcher adopted two different scoring schemes in this study. One scheme took into account the structure of the concept maps produced by the subjects. This scoring scheme counted the number of map components and basically weighted map components closely related to hierarchical structures: branchings, crosslinks, and hierarchies. This scheme emphasized the complexity of the hierarchical network forms that are supposed to reflect mental structures (Canas 2003, Markham et al. 1994, Novak and Gowin 1984, Stuart 1985). The second scoring scheme explored the nature of the interrelationships between two concepts and the linguistic structures of propositions. This scheme emphasized the correctness of the propositional statements that were supposed to reflect students' understanding of concepts covered in instruction (Rice et al. 1998, Roberts 1999, Ruiz-Primo et al. 1997, Rye and Rubba 2002).

For the structural scheme, the researcher adopted a modified version of Novak and Gowin's scoring method; this modified scoring method was used by Markham, Mintzes and Jones (1994). This method counts the numbers of concepts, relationships, branchings, hierarchies, crosslinks and examples. In the experiments of this study, participants used the concepts the researcher had designated in advance. Therefore, the criterion of examples was logically eliminated in this scoring. Each concept and each valid relationship received one point respectively. Branchings had two types of scoring weights. The first branching received one point; the successive branchings received three points. Each hierarchy received five points. Each valid crosslink received ten points because crosslinks were regarded as the evidence of concept map complexity.

For the relational scheme, the researcher utilized a combination of a propositional matrix and a propositional inventory. The propositional matrix listed 435 possible pairs composed of the thirty geospatial concepts that were used in the experiment sessions (Appendix B). The researcher classified the 435 pairs into the following three categories: correct, partially correct and incorrect. For the pairs that belong to the correct category, the researcher formulated possible propositional statements (Appendix C).

In order to develop the matrix and inventory, the researcher identified experts' definitions of the thirty geospatial concepts by referring to two books and a GIS dictionary on the website of ESRI, a leading GIS software vendor. One of the two books was a textbook (DeMers 2005) used in one of the introductory-level GIS courses. The other book (Witthuhn, Brandt and Demko 1976) was frequently referred to in a chapter on spatial concepts in the DeMers textbook. The definitions extracted from the materials reflected experts' definitions of geospatial concepts. For example, the definition of cluster was as follows: "cluster demonstrates a type of distribution with a high density of features."

After the researcher obtained definitions, he examined those definitions to identify the pairs that belong to a correct category. In the case of "cluster," the terms of "cluster" and "distribution" and "cluster" and "density" were the pairs of the correct category because those terms were included in the definition of cluster. In the next step, the researcher formulated correct propositional statements by referring to the definition statements and correct pairs. As an example, for "cluster," the researcher formulated the following four statements: 1) cluster demonstrates a high density, 2) cluster demonstrates a type of distribution, 3) density is a measure of cluster, and 4) distribution representing a convergent condition is cluster. Establishing correct pairs and correct propositional statements enabled each of the thirty spatial concepts to have one or more correct pairs and two or more correct propositional statements.

The researcher also examined the possible pairs and propositional statements that may not belong to the correct category. For instance, the terms of "cluster" and "diffusion" may bring the following statement: "cluster is one of the results of diffusion;" the relationship between "cluster" and "spatial relationship" may be expressed by the following statement: "cluster can be used to describe a spatial relationship." These propositional statements are not the definition of "cluster" formulated by experts, nor are they overarching concepts; however, those statements are correct only under certain circumstances. Thus, the combination of "cluster" and "diffusion" and the combination of "cluster" and "spatial relationship" are partially correct pairs and can formulate partially correct statements. The researcher assigned such statements to a partially correct category. After the researcher identified the pairs that belong to the correct and partially correct category, he assigned the possible pairs that belonged to neither the correct category nor the partially correct category to an incorrect pair category.

To initiate scoring with the relational, the researcher rewrote all of the propositional pairs and the statements described in each of the obtained concept maps into a matrix. The researcher scored the pairs and statements based on the three categories of propositional pairs and statements. The score range of propositional pairs was from 0 to 2 points. If a pair met one of the pairs that belong to the correct category, the pair received 2 points; if a pair was regarded as a partially correct pair, the pair received one point; if a pair belonged to neither a correct pair nor a partially correct pair, the pair did not receive any point. The score range of propositional statements was from 0 to 4 points. A correct statement received 4 points; a partially correct statement received 2 points; an incorrect statement and a link without a statement did not receive any point. A combination of pair scores and statement scores established nine different accuracy categories (Table 7). A correct statement belonged to only a correct pair. A partially correct statement belonged to a correct pair or a partially correct pair. The range of the combined scores was from 0 to 6 points. Thus, if a participant's proposition met experts' definition, the proposition received 6 points in total.

Table 7. The relational score weight matrix

	Correct Pair	Partially Correct Pair	Incorrect Pair
Correct Statement	6 points	No assigned	No assigned
Partially Correct Statement	4 points	3 points	No assigned
Incorrect Statement	2 points	1 point	0 point
Missing Statement	2 points	1 point	0 point

Experimental Procedure

In this study, three experiment sessions occurred in the beginning, middle, and end of the two semesters of data collection (Table 8). In all three experiments, the researcher asked participants to create a concept map about the primary concept, space, by using concept mapping software, and then rate their confidence in the accuracy of the concept map and the understanding of spatial concepts with Likert scale questions. The researcher also asked participants to revise a concept map in the second and third sessions. In the second session, participants revised a concept map they created in the first session. In the third session, participants revised a concept map they made in the second session. Participants rated confidence in the creation of revised maps as well. In addition, participants performed spatial tasks in the first and third experiment sessions. The procedural order was as follows: 1) answer questions about subjects' personal information (Appendix E); 2) make a concept map about the primary concept, space; 3) revise a concept map created in the previous session; 4) rate confidence in the concept mapping and the understanding of spatial concepts with two or three Likert scale questions; 5) perform two spatial tasks. Demographic data was collected only in the first session; the second and fourth steps occurred in all three sessions; the third step occurred in the second and third sessions; the fifth step occurred in the first and third sessions (Table 8).

Table 8. Activities and procedural order in the three experiment sessions

Step	Activity	1st Session	2nd Session	3rd Session
1	Answering question about subjects' personal information	X		
2	Making a concept map about the primary concept, space	X	X	X
3	Revising a concept map created in the previous session		X	X
4	Rating confidence on Likert scales	X	X	X
5	Performing spatial tasks	X		X

Data Analysis

The data analysis of this study related to each of the three research questions. The first research question was what differences existed between students' understandings of spatial concepts at the beginning, middle, and end of an introductory-level GIS course. In order to study this research question, the researcher analyzed differences between the scores of concept maps that were created and revised in three experiment sessions by conducting the Friedman's ANOVA test and the follow-up Wilcoxon signed-rank test. The Friedman's ANOVA test is a non-parametric test and is used for testing differences between two or more experimental conditions to which the same participants contribute. The Wilcoxon signed-rank test is a non-parametric post hoc test for the Friedman's

ANOVA test. The Wilcoxon signed-rank test is used for comparing two experimental conditions in which the same participants take part.

The second research question was what geospatial misconceptions students may possess while they were taking an introductory-level GIS course. In the analysis of this research question, the researcher focused on the misunderstandings of map projection, scale, and distortion. Map projection causes distortion; however, some students may regard scale as the cause of distortion. The misconceptions of these geospatial concepts can be characterized as scientifically irrelevant knowledge, which hinders students from thinking spatially and using maps and GIS appropriately. In order to identify those misconceptions, the researcher extracted the incorrect statements of map projections, scale, and distortion from participants' concept maps and examined them to see if those misconceptions had disappeared during a single semester.

The third research question was which geospatial concepts were easy or hard for undergraduate university students to understand. The researcher referred to Golledge's geospatial concept lexicon and ontology (See Table 3) to infer the complexity level of the thirty geospatial concepts that were used for concept mapping in experiment sessions (Table 9). The researcher conducted the Kruskal−Wallis test and the follow-up Mann−Whitney test to examine if the scores were significantly different between the three complexity categories: primitive and simple concepts, difficult concepts, and complicated and complex concepts. The Kruskal−Wallis test is a non-parametric test and is used for testing differences between two or more experimental conditions to which different subjects contribute. The Mann−Whitney test is a non-parametric post hoc test for the Kruskal−Wallis test. The Mann−Whitney test is used for comparing two experimental conditions in which different subjects participate.

For the statistical analyses of concept complexity, the researcher calculated concept-based scores by examining a propositional statement matrix that was used for scoring concept maps by using the relational. In this matrix, each propositional statement was categorized into a correct, partially correct, or incorrect statement either. A concept that was found in a correct statement received 4 points; a concept that was included in a partially correct statement received 2 points; a concept that belonged to an incorrect statement did not receive any point.

Table 9. Geospatial concepts categorized based on complexity levels

Complexity Level	Concepts	Complexity Level	Concepts
Primitive	location	Difficult	diffusion
	point		dispersion
Simple	arrangements		linkage
	boundary		pattern
	direction		polygon
	distance		three dimensions
	distribution		two dimensions
	line	Complicated	buffer
	proximity		network
	shape		scale
	size	Complex	association
	spatial relationship		distortion
Difficult	cluster		map projection
	coordinate		overlay
	density		topology

Summary

This study assessed students' spatial concept knowledge and tracked their conceptual development in a single semester. The research design was a single-group time series design. Each participant attended a training session and took three experiment sessions in the beginning, middle, and end of a semester. The concept map was adopted for assessing students' spatial concept knowledge. The researcher scored obtained concept maps by using two different scoring schemes: the structural and the relational. The structural mainly assessed the structural complexity of concept maps; the relational mainly assessed the correctness of propositional pairs and statements on the basis of a combination of a propositional matrix and a propositional inventory. Copies of the instrumentation are found in Appendices A through E. The results of analyzing obtained data are the subject of Chapter IV.

CHAPTER IV

FINDINGS AND ANALYSIS

Introduction

As stated in Chapter I, this study examined college students' conceptual knowledge related to GIS learning and use. This study had three research questions: 1) what differences existed between students' understandings of spatial concepts at the beginning, middle, and end of an introductory-level GIS course; 2) what geospatial misconceptions students may possess while taking an introductory-level GIS course; and 3) which geospatial concepts are easy or hard for undergraduate university students to understand. In order to answer these three questions, the researcher obtained sixty geospatial concept maps produced by twelve participants at the beginning, middle, and end of a semester of GIS instruction respectively. They were scored utilizing two types of scoring schemes: the structural and the relational.

This chapter first discusses the descriptive statistics of data obtained from the experiments. It is organized in terms of the three specific research questions. It first reports the results of concept map score analyses; it then examines participants' spatial misconceptions; it finally describes spatial concept complexity in terms of students' understandings. In addition, this chapter describes a comparative analysis between two GIS courses: GEOG390 and FRSC 461.

Descriptive Statistics

Participants' Attributes

At the beginning of the first experiment session, the researcher asked participants to complete a demographic questionnaire (Appendix E). Two sophomore students, five junior students, and five senior students participated in this study (Table 10). This means that university junior and seniors comprised 41.7 percent of the participants respectively, and the ratio of sophomores was 16.7 percent. As to participants' majors, four participants majored in Geography and the discipline of Wildlife Fisheries and Sciences respectively. Three participants' major was Spatial Sciences; a single participant's major was Marketing. As to the ratio of spatial science majors to non-spatial science majors, 58.3 percent of the participants majored in disciplines related to spatial science including geography and spatial sciences; 41.7 percent of the participants majored in non-spatial science disciplines including marketing and wildlife and fisheries sciences. As to participants' GIS courses, seven participants (58.3 percent of the participants) were taking GEOG 390, and five participants (41.7 percent of the participants) were taking FRSC 461. As to participants' spatial science course work experience, seven participants (58.3 percent of the participants) registered for a GIS or remote sensing course for the first time; five participants (41.7 percent of the participants) registered for a GIS or remote sensing course in the past. The researcher also asked the participants about their experience of map use, confidence in map reading, and a reason of enrollment in a GIS course (Table 11).

Table 10. Distribution of participants' academic characteristics

Gender	Male 11		Female 1	
Age	20 Years Old 4	21 Years Old 4	22 Years Old 2	23 Years Old 2
Academic Year	Freshman 0	Sophomore 2	Junior 5	Senior 5
Major	Geography 4	Spatial Sciences 3	Marketing 1	Wildlife & Fisheries Sciences 4
GIS Course	GEOG390 7		FRSC461 5	
Spatial Science Course Work Experience	GEOG390 or FRSC461 is the first spatial science course. 7		GEOG390 or FRSC461 is not the first spatial science course. 5	

Table 11. Distribution of participants' attitudes toward GIS and map use

Questions	Answers	Number of Participants
How long have you used GIS software in a week this semester?	Less than one hour	0
	More than one hour and less than two hours	0
	More than two hours and less than three hours	5
	More than three hours and less than five hours	3
	More than five hours and less than eight hours	2
	More than eight hours	2
When did you start using a map?	I didn't start using a map until I became a college student.	1
	I start using a map when I was a high-school student.	1
	I start using a map when I was a junior high-school student.	4
	I start using a map when I was an elementary student.	6
How often do you use a map?	About once a week	5
	About once a month	6
	About once a half year	1
	About once a year	0
	Never	0
I think I am good at reading a map.	Strongly disagree	0
	Disagree	0
	Neither agree nor disagree	2
	Agree	8
	Strongly agree	2
I think I can enjoy reading a map.	Strongly disagree	0
	Disagree	0
	Neither agree nor disagree	1
	Agree	6
	Strongly agree	5
Why did you decide to take a GIS course?	My advisor or a professor recommended taking this course.	4
	This course is required.	2
	The knowledge and skills obtained in this course are marketable.	7
	This course fits my interest.	4

Spatial Task Scores

Participants performed spatial tasks (Appendix A) in the first and third experiment sessions. The pre-test and post test both had two questions. Answers to each question were scored on a three-point scale; therefore, a full score was 6 points (Table

12). Eight participants obtained higher scores in the post-test than the pre-test; three participants obtained the same scores in the pre- and post-tests; one participant obtained worse scores in the post-test than the pre-test (Figure 3).

Table 12. Descriptive statistics of participants' spatial task scores

	Mean	Median	Standard Deviation	Minimum Score	Maximum Score
Pre-test	3.25	3.5	2.05	0	6
Post-test	4.67	5.0	1.58	1	6

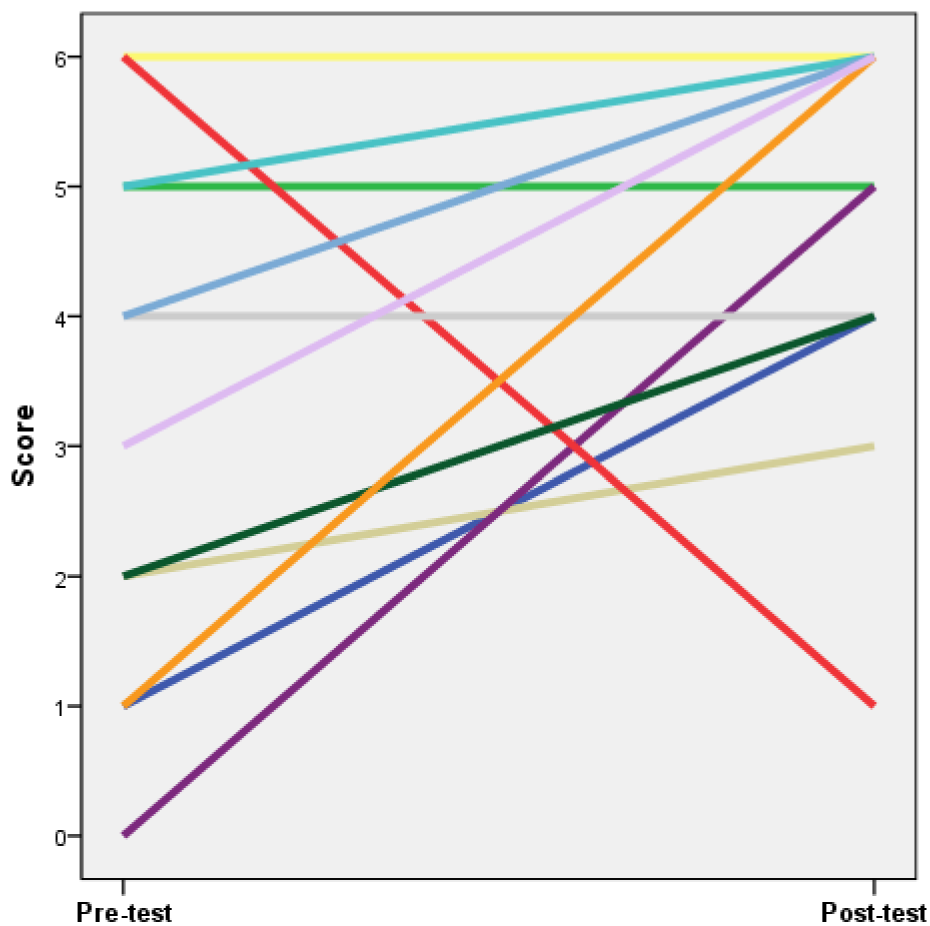

Figure 3. The distribution of pre- and post-spatial skill test scores

Confidence Degree of Concept Mapping and Understandings

In the three experiment sessions, the researcher asked participants to put tick marks on bars that were accompanied by the following three statements: 1) I constructed the map without uncertainty; 2) I understand spatial concepts sufficiently to use GIS software; and 3) The concept map I created in the previous session has been improved. The first statement was asked to determine the degree of participants' confidence in completing a concept map; the purpose of second and third question was to examine the degree of confidence in understanding geospatial concepts and improving a concept map previously created respectively. The third statement was posed in only the second and third experiment session after participants' revised a concept map they created in the previous session.

Each bar represented the Likert scale of confidence. The most left side of a bar represented the largest degree of confidence; in contrast; the most right side of a bar represented the smallest degree of confidence. The length measured from the scales was transformed to index values that range from 0 to 1. The value 0 meant the smallest degree of confidence; the value 1 meant the largest degree of confidence. The mean and median values of confidence in completing a concept map and understanding geospatial concepts gradually increased throughout the semester (Table 13, Figures 4, 5, and 6). Both the mean and median values of the second session were larger than those of the first session; the mean and median values of the third session were larger than those of the second session.

Table 13. Descriptive statistics of participants' confidence degree values

	Session	Mean	Median	Standard Deviation	Minimum	Maximum
Completing a concept map	1st	0.505	0.460	0.186	0.307	0.927
	2nd	0.621	0.635	0.251	0.139	0.978
	3rd	0.653	0.741	0.218	0.095	0.839
Understanding geospatial concepts	1st	0.630	0.602	0.177	0.394	1.000
	2nd	0.692	0.690	0.208	0.263	0.985
	3rd	0.745	0.814	0.185	0.336	1.000
Improving a concept map	2nd	0.700	0.701	0.204	0.263	1.000
	3rd	0.711	0.745	0.201	0.343	1.000

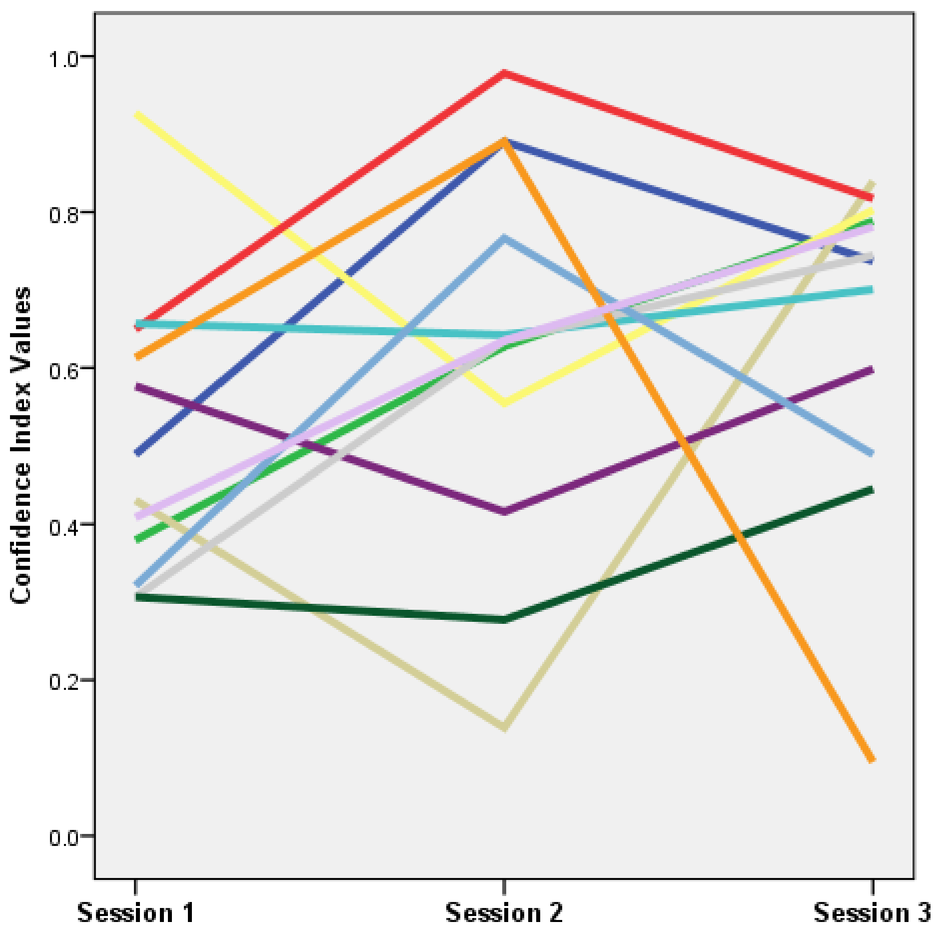

Figure 4. The distribution of confidence index values for completing a concept map

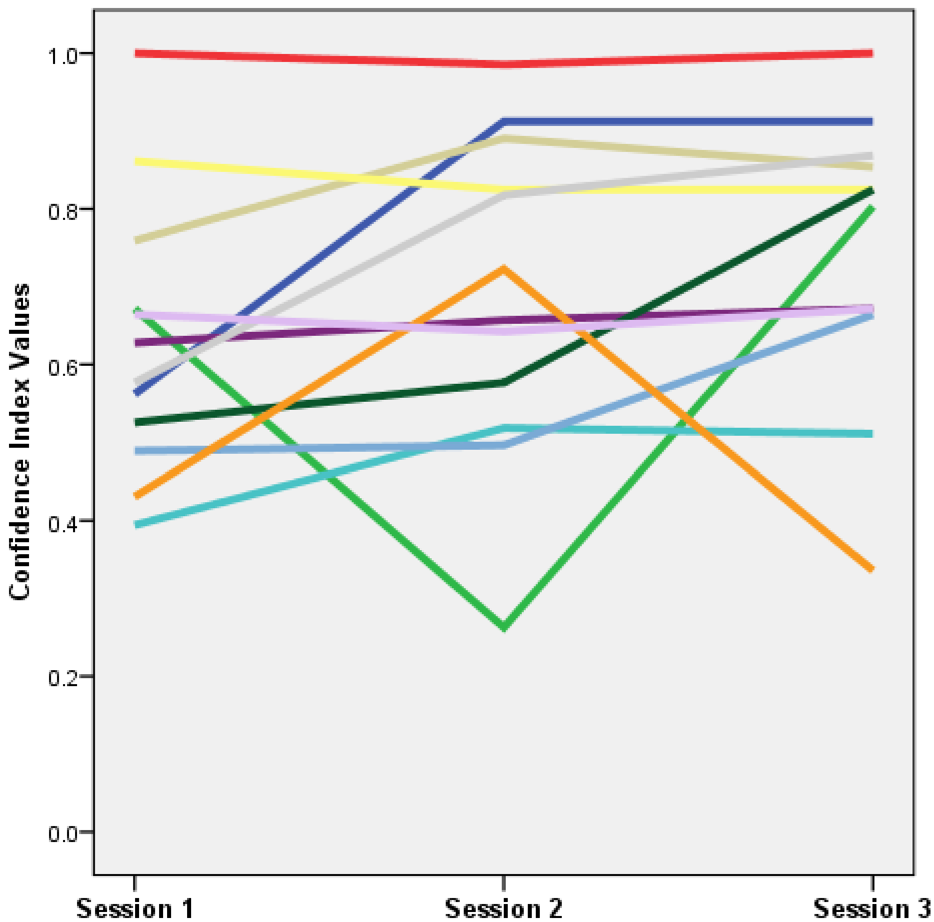

Figure 5. The distribution of confidence index values for understanding spatial concepts

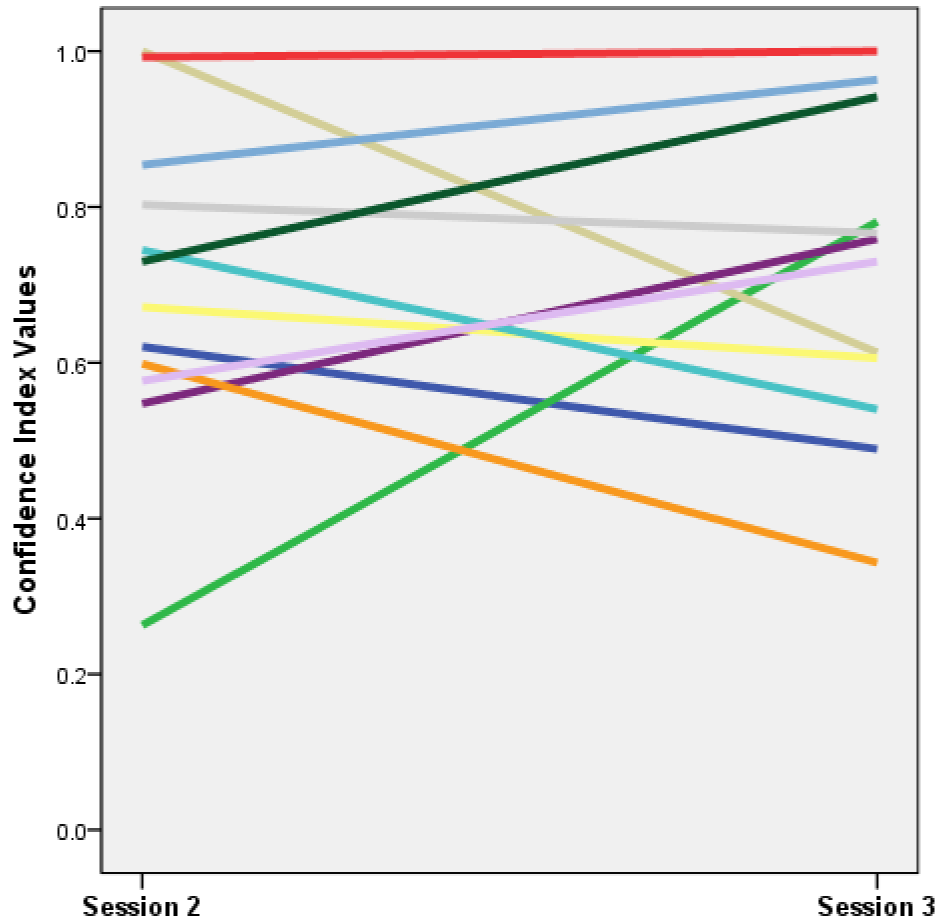

Figure 6. The distribution of confidence index values for improving a concept map

Participant-based Concept Map Scores

Twelve participants satisfactorily created concept maps about space in the three experiment sessions and revised concept maps were produced in the second and third experiment sessions. Consequently, the researcher obtained thirty-six original concept maps and twenty-four revised concept maps and scored them utilizing two types of the scoring schemes: the structural and the relational.

The scores of the three original maps varied by scoring method (Tables 14 and 15, Figures 7 and 8). The mean and median values of scores evaluated using the structural in the second session were the lowest scores obtained in the three experiment sessions. The mean value of scores evaluated using the relational in the first session was the lowest scores obtained in the three experiment sessions. The mean values of scores evaluated using the relational gradually increased throughout the three experiment sessions.

The scores of the original maps and revised maps also varied by scoring method (Table 14 and Table 15). The mean and median values of the scores of revised maps were basically larger than those of the original first draft maps in both of the cases of the structural and the relational. However, in the case of the structural, the median value of the scores of first draft maps created in the first session was larger than that of the scores of maps revised in the second session.

Table 14. Descriptive statistics of participants' structural concept map scores

	Session	Mean	Median	Standard Deviation	Minimum	Maximum
Newly created concept maps	1st	92.42	93.5	12.47	65	116
	2nd	89.58	88.0	15.13	72	116
	3rd	98.00	97.5	25.01	70	164
Improved concept maps	2nd	94.83	89.5	15.80	84	140
	3rd	94.92	92.5	15.77	71	123

Table 15. Descriptive statistics of participants' relational concept map scores

	Session	Mean	Median	Standard Deviation	Minimum	Maximum
Newly created concept maps	1st	79.33	84.5	22.17	40	109
	2nd	83.08	86.0	19.55	59	125
	3rd	86.00	80.5	24.31	52	136
Improved concept maps	2nd	91.33	97.0	23.12	55	123
	3rd	85.83	89.0	19.52	52	118

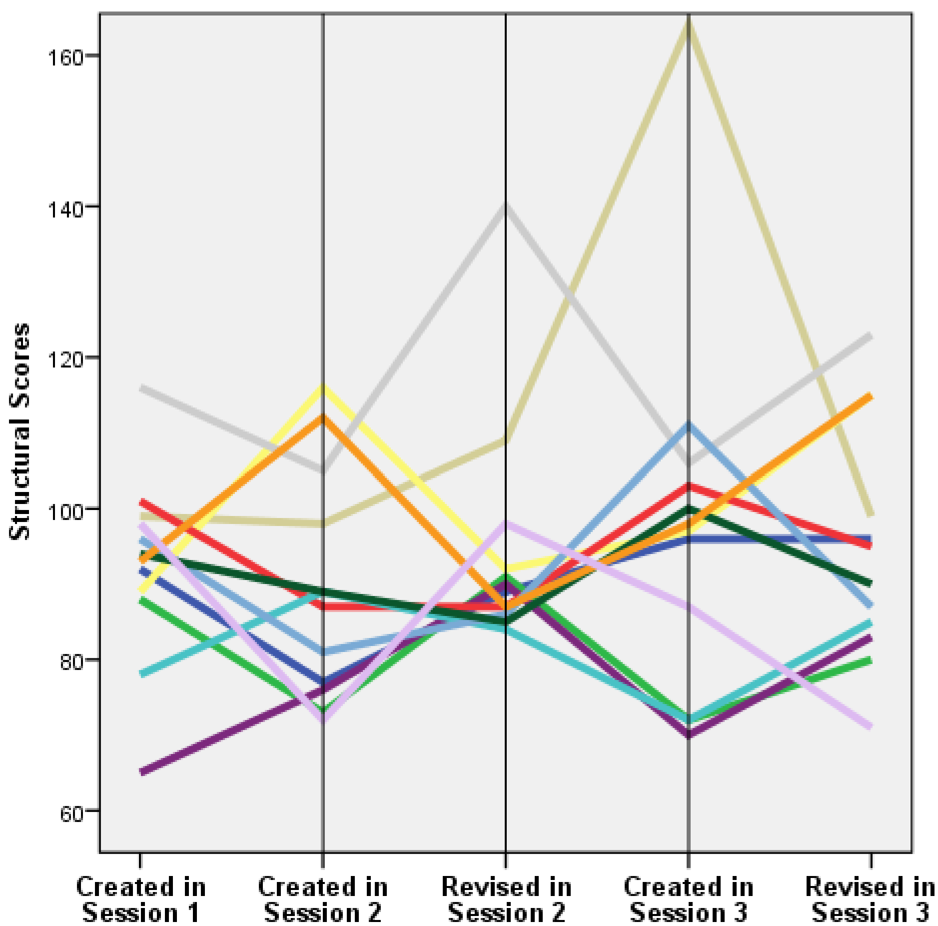

Figure 7. The distribution of structural scores

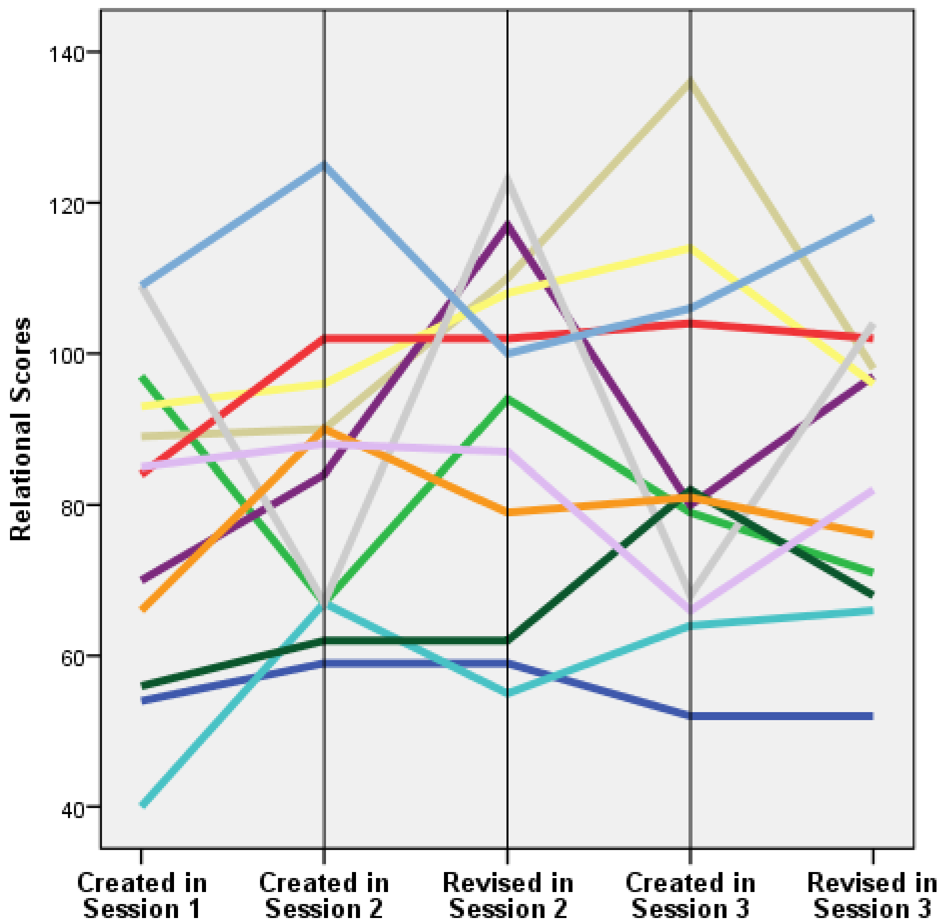

Figure 8. The distribution of relational scores

In the third experiment session, Participant A constructed a map (Figure 9) that took him or her twenty-two minutes; Participant B completed a map (Figure 10) in the first session by spending seventeen minutes. Participant A's concept map is an exemplar of high-score maps; Participant B's map is an exemplar of low-score map. The structural score of Participant A's map is 162; Participant B's structural score is 65. This score difference arose from the number of concepts, valid relationships, and valid crosslinks. Participant A used thirty concepts; on the other hand, Participant B used seventeen concepts in total. Difference in the use of concepts caused a gap in valid relationships. Participant A's map includes thirty-five valid relationships; Participant B's map has fourteen valid relationships. The biggest factor in the difference of map scores is the number of crosslinks. Participant A added six valid crosslinks; Participant B did not make any crosslink. The score weight of crosslinks is larger than the other weights. This accelerated the score difference between the two participants. The relational score of Participant A's map is 136; Participant B's relational score is 70. Participant A's map includes thirty-five correct or partially correct statements and thirty-eight correct or partially correct pairs; while, Participant B's map contains fourteen correct or partially correct statements and fourteen correct or partially correct pairs Although Participant B constructed a map with a limited number of propositions, he or she did not add any incorrect statement and pair. In contrast, Participant A made eleven incorrect statements and five incorrect pairs. This implied that Participant B added only concepts that he or she is certainly familiar with.

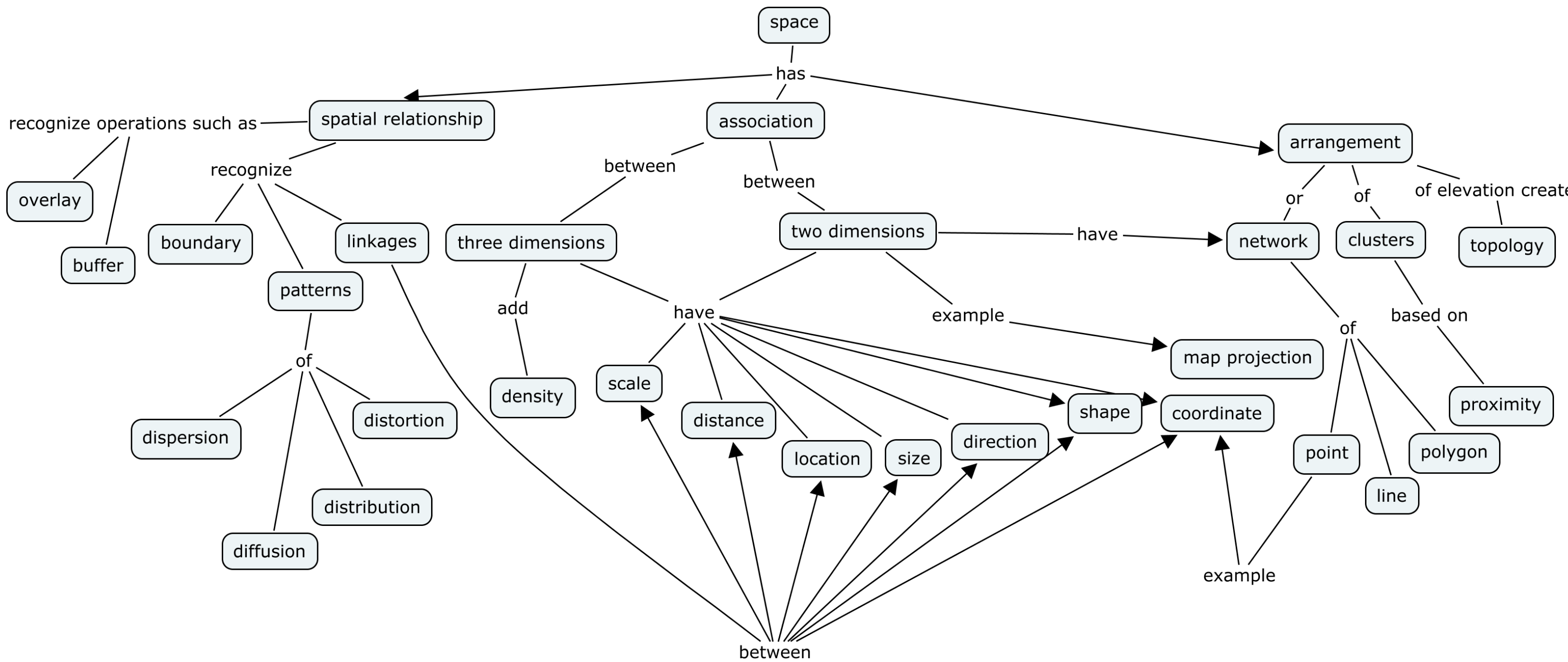

Figure 9. Participant A’s map

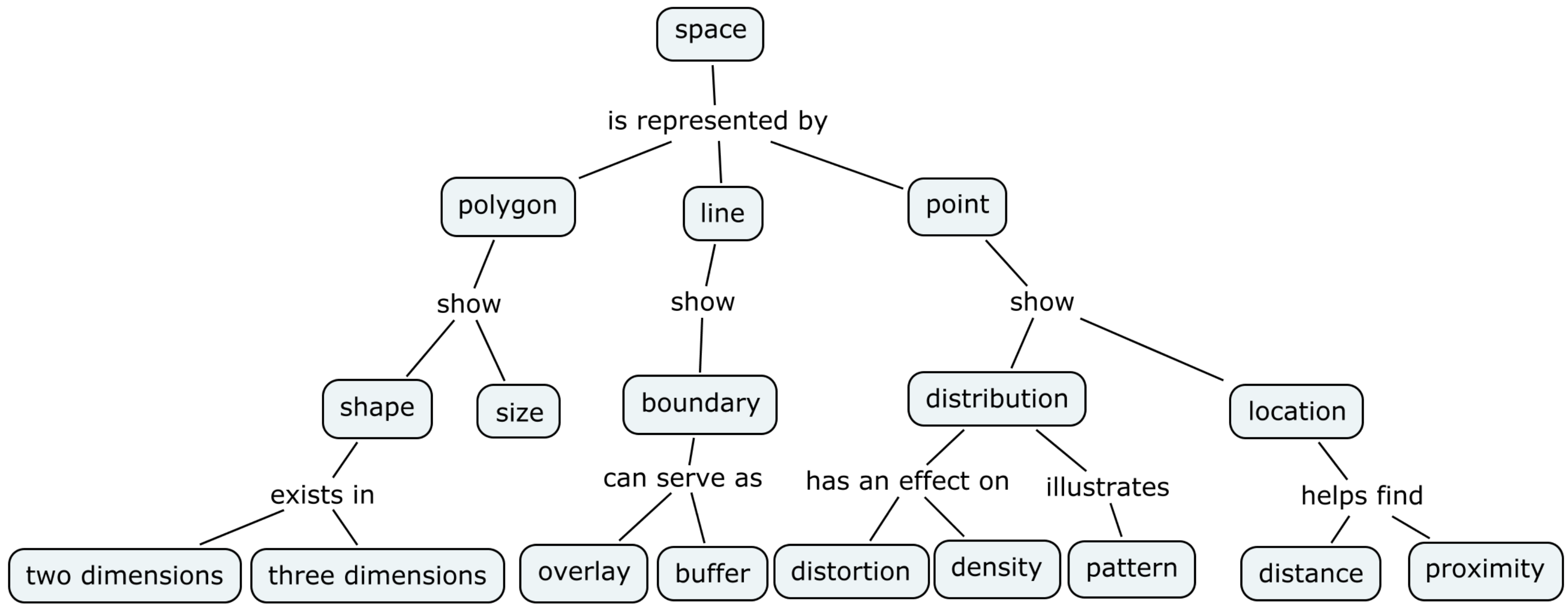

Figure 10. Participant B’s map

Concept-based Concept Map Scores

The researcher calculated scores for each concept (Table 16 and Figure 11). Each of the propositional statements written by participants had two concepts at either end of its statement. The researcher gave 4 points to a concept that was identified in a correct propositional statement; a concept that was included in a partially incorrect statement was assigned 2 points; a concept related to an incorrect statement had no point. The researcher aggregated these obtained scores and classified them into the following five complexity levels: the primitive level, the simple level, the difficult level, the complicated level, and the complex level. For the inferential statistics analysis of the concept-based scores, the researcher integrated these five levels into the following three levels: the primitive and simple level, the difficult level, and the complicated and complex level. The mean and median values of the primitive and simple level were the largest among the values of the three levels; the mean and median values of the complicated and complex level were the smallest among the values of the three levels (Table 17). Figure 11 shows there were two outliers. The scores for the concepts coordinate and the score of map projection were extraordinarily high in the difficult category and the complicated and complex category respectively.

Table 16. Classified concept-based scores

Complexity Level	Concepts	Scores	Complexity Level	Concepts	Scores
Primitive	location	227	Difficult	diffusion	35
	point	155		dispersion	88
Simple	arrangements	59		linkage	82
	boundary	106		pattern	107
	direction	73		polygon	111
	distance	131		three dimensions	109
	distribution	189		two dimensions	180
	line	158	Complicated	buffer	48
	proximity	76		network	64
	shape	280		scale	88
	size	61	Complex	association	45
	spatial relationship	191		distortion	76
Difficult	cluster	50		map projection	165
	coordinate	223		overlay	31
	density	47		topology	32

Table 17. Descriptive statistics of classified concept-based scores

	Mean	Median	Standard Deviation	Minimum Score	Maximum Score
Primitive & Simple	142.17	143.0	70.90	59	280
Difficult	103.20	97.5	59.33	35	223
Complicated & Complex	68.63	56.0	43.88	31	165

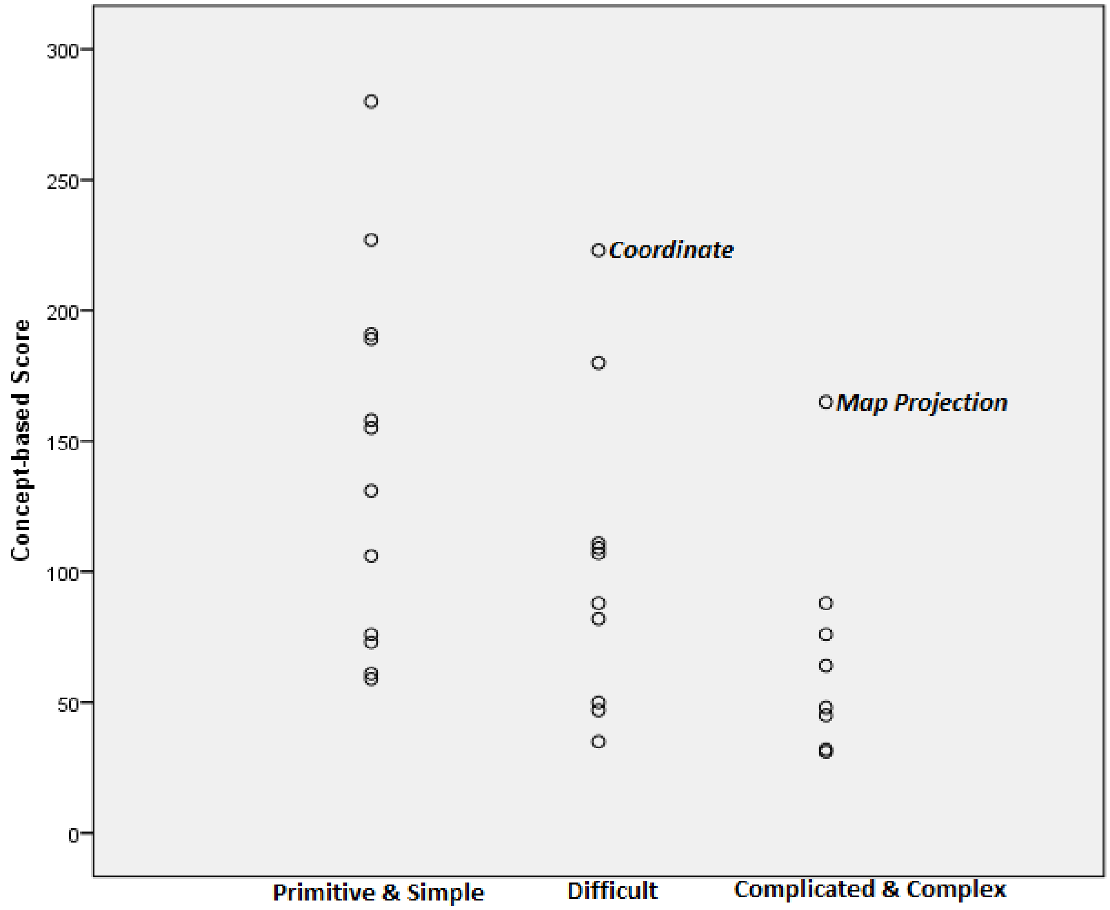

Figure 11. The distribution of concept-based scores

Research Question 1

The first research question was what differences exist between students' understandings of spatial concepts at the beginning, middle, and end of an introductory-level GIS course. In order to answer this question, the researcher conducted two analyses of the concept map scores participants created in three experiment sessions and revised in the second and third sessions. The concept map scores came from two types of scoring schemes: the structural and the relational.

The first analysis was the Friedman's ANOVA test. In this test, there were four combinations in each of the scoring methods (Table 18 and Table 19). The significance level of this test was set at 0.05. For the concept map scored with the structural, the scores did not change significantly over a semester (Table 18). In contrast, the results of the relational were different (Table 19). The scores for concept maps created originally in the first session and the concept maps revised in the second and third sessions changed significantly ($\chi^2(2) = 6.68$, $p = 0.04$). Scores did not change significantly for other concept maps.

The second analysis was the Wilcoxon signed-rank test. This test was used to confirm whether results of the analysis of scores evaluated by the relational were significantly different (Table 20). A Bonferroni correction was applied and so all effects are reported at a 0.0167 level of significance. It appeared that scores changed significantly in a comparison between the maps created in the first session (*Mdn* = 84.5) and the maps revised in the second session (*Mdn* = 97.0), $Z = -2.51$, $p = 0.012$. The other two comparisons did not indicate significant difference.

Table 18. Result of the Friedman's ANOVA test of the structural scores

Combination of Three Groups	χ^2	p
Created in session 1 - Created in session 2 - Created in session 3	1.50	0.47
Created in session 1 - Created in session 2 - Revised in session 3	3.36	0.19
Created in session 1 - Revised in session 2 - Created in session 3	1.32	0.52
Created in session 1 - Revised in session 2 - Revised in session 3	0.30	0.86

Table 19. Result of the Friedman's ANOVA test of the relational scores

Combination of Three Groups	χ^2	p
Created in session 1 - Created in session 2 - Created in session 3	3.50	0.17
Created in session 1 - Created in session 2 - Revised in session 3	4.87	0.09
Created in session 1 - Revised in session 2 - Created in session 3	3.17	0.21
Created in session 1 - Revised in session 2 - Revised in session 3	6.68	0.04

Table 20. Result of the Wilcoxon signed-rank test of the relational scores

Pair of Two Groups	Z	p
Created in session 1 - Revised in session 2	-2.51	0.012
Created in session 1 - Revised in session 3	-1.65	0.099
Revised in session 2 - Revised in session 3	-1.51	0.130

Comparative Analysis between GEOG390 and FRSC 461

As an extensional analysis of the first research question, the researcher statistically analyzed differences between participants who enrolled in GEOG 390 and those who enrolled in FRSC 461 (Table 21 and Table 22). This statistical analysis examined if there was any significant difference in the two participant groups in terms of concept map score increase/decrease. In order to conduct this analysis, the researcher calculated the differences of two concept map scores for the structural and the relational. The differences are extracted from the following five equations: 1) a score of map created in the second session – a score of map created in the first session, 2) a score of map created in the third session – a score of map revised in the first session, 3) a score of map created in the third session – a score of map created in the second session, 4) a score of map revised in the second session – a score of map originally created in the first session, and 5) a score of map revised in the third session – a map originally created in the second session. The number of participants who enrolled in GEOG 390 was seven; the number of participants who enrolled in FRSC 461 was five. The significance level of this test was set at 0.05. The results of the Mann−Whitney test indicated that there was not any significant difference between the two groups in either of the structural scores and the relational scores (Table 23 and Table 24).

Table 21. Descriptive statistics of structural score differences by GIS courses

Pair of Concept Maps	Course	Median	Minimum	Maximum
Created in session 1 - Created in session 2	GEOG 390	-11	-26	27
	FRSC 461	-5	-15	11
Created in session 1 - Created in session 3	GEOG 390	4	-11	8
	FRSC 461	6	-16	65
Created in session 2 - Created in session 3	GEOG 390	1	-19	19
	FRSC 461	11	-17	66
Created in session 1 - Revised in session 2	GEOG 390	0	-14	25
	FRSC 461	3	-10	10
Created in session 2 - Revised in session 3	GEOG 390	7	-1	19
	FRSC 461	1	-4	7

Table 22. Descriptive statistics of relational score differences by GIS courses

Pair of Concept Maps	Course	Median	Minimum	Maximum
Created in session 1 - Created in session 2	GEOG 390	5	-42	24
	FRSC 461	6	-30	27
Created in session 1 - Created in session 3	GEOG 390	10	-41	21
	FRSC 461	24	-18	47
Created in session 2 - Created in session 3	GEOG 390	-4	-22	18
	FRSC 461	12	-19	46
Created in session 1 - Revised in session 2	GEOG 390	14	2	47
	FRSC 461	6	-9	21
Created in session 2 - Revised in session 3	GEOG 390	0	-14	37
	FRSC 461	4	-7	8

Table 23. Result of the Mann−Whitney test of structural score differences

Pair of Concept Maps	*U*	*p*
Created in session 1 - Created in session 2	-0.33	0.74
Created in session 1 - Created in session 3	-0.73	0.46
Created in session 2 - Created in session 3	-0.73	0.47
Created in session 1 - Revised in session 2	-0.16	0.87
Created in session 2 - Revised in session 3	-1.14	0.25

Table 24. Result of the Mann−Whitney test of relational score differences

Pair of Concept Maps	*U*	*p*
Created in session 1 - Created in session 2	-0.08	0.94
Created in session 1 - Created in session 3	-1.22	0.22
Created in session 2 - Created in session 3	-1.22	0.22
Created in session 1 - Revised in session 2	-0.81	0.42
Created in session 2 - Revised in session 3	-0.33	0.74

Research Question 2

The second research question was what geospatial misconceptions students may possess while taking an introductory-level GIS course. To answer this research question, the researcher examined participants' incorrect propositional statements concerning the concepts of distortion, scale, and map projection.

Of twelve participants, six participants indicated misconceptions about distortion, scale, and map projection (Table 25). The researcher tracked if their misconceptions had disappeared during the three experiment sessions. There were the two transition patterns of misconceptions. The first transition pattern was that four participants had held misconceptions during the three experiment sessions. First, Participant A regarded scale as the cause of distortion in the three sessions. Second, Participant B did not indicate that he thought that scale causes distortion explicitly in the first session; however, he clearly showed that misconception in both of the second and third sessions. Third, Participant C described scale causes distortion in the first and second sessions and emphasized that map projection represents spatial relationship. Although he did not indicate a relationship between scale and distortion in the third session, he thought size causes distortion. He did not relate distortion to map projection. Fourth, Participant D continuously changed his conception of distortion. In the first session, the cause of distortion was scale. In the second session, the cause was distribution. In the third session, the cause was high density. Although he thought map projection visually relates to shape, size, and spatial relationship, he did not infer that the cause of distortion is map projection. The second transition pattern is that the two participants showed improved statements in the second and third sessions. Both Participant E and Participant F described scale causes distortion in the first session. However, they represented the cause of distortion is due to map projection.

Table 25. Participants' propositional statements of distortion, scale, and map projection

Participants	Session 1	Session 2	Session 3
A	Scale consists of map projection.	Scale can be map projection.	Scale can have distortion.
B	Map projection displays a network.	Scale form distortion; Shape is projected by scale.	Scale may create distortion.
C	Scale can cause distortion; Scale affects size; Spatial relationship encompasses map projection.	Scale affects distortion; Size affected by scale; Map projection represents spatial relationship.	Scale affects size; Size can create distortion; Spatial relationship visualized using a map projection.
D	Scale can easily cause distortion; Map projection visually changes the shape and size.	Distribution can result in distortion; Map projection helps to illustrate spatial relationship.	Density in large amounts leads to distortion.
E	Distortion can be caused by scale; Distortion can be caused by topology; Map projection if wrong distortion.	Map projection often causes distortion.	Map projection can be distortion.
F	Scale but will always result in some form of distortion.	Map projection has some degree of distortion.	Map projection, which introduces some distortion; Map projection, which is meaningless without scale.

Research Question 3

The aim of the third research question was to examine if there were any differences between simple geospatial concepts and complex geospatial concepts in terms of students' understandings. In order to answer this question, the researcher conducted two analyses of the concept-based scores that were classified into the following three complexity levels: the primitive and simple level, the difficult level, and the complicated and complex level (See Table 16). In these statistical analyses, the researcher also tested with a set of concept-based scores that excluded two outliers: the concept of coordinate and the concept of map projection.

The first analysis was the Kruskal−Wallis test. This test had a three-group combination in the case of a full set of the thirty concepts (Table 26) and the case of a set of twenty-eight concepts but the two outliers (Table 27). The significance level of this test was set at 0.05. It appeared that the scores were significantly different between the three levels in both of the case of a full set of concepts ($H(2) = 6.51$, $p = 0.039$) and the case of a set of concepts excluding the two outliers ($H(2) = 9.14$, $p = 0.010$).

The second analysis was the Mann−Whitney test. This test was used to confirm whether results of the previous Kruskal−Wallis test were significantly different. A Bonferroni correction was applied and so all effects are reported at a 0.0167 level of significance. It appeared that the scores were significantly different in a comparison between the primitive and simple concept level and the complicated and complex concept level in the case of a full set of concepts ($U = -2.35$, $p = 0.012$) (Table 28). In the case of a set of concepts excluding the two outliers, the scores were also significantly different in a comparison between the primitive and simple concept level and the complicated and complex concept level, ($U = -2.67$, $p = 0.005$) (Table 29).

Table 26. Result of the Kruskal−Wallis test of a full set of concepts

Combination of Three Groups	*H*	*p*
Primitive & Simple - Difficult - Complicated & Complex	6.51	0.039

Table 27. Result of the Kruskal−Wallis test of a set of concepts but outliers

Combination of Three Groups	*H*	*p*
Primitive & Simple - Difficult - Complicated & Complex	9.14	0.010

Table 28. Result of the Mann−Whitney test of a full set of concepts

Pair of Two Groups	*U*	*p*
Primitive & Simple - Difficult	-1.25	0.228
Primitive & Simple - Complicated & Complex	-2.35	0.016
Difficult - Complicated & Complex	-1.65	0.101

Table 29. Result of the Mann−Whitney test of a set of concepts but outliers

Pair of Two Groups	*U*	*p*
Primitive & Simple - Difficult	-1.78	0.080
Primitive & Simple - Complicated & Complex	-2.67	0.005
Difficult - Complicated & Complex	-1.90	0.056

Summary

In summary, the analyses of participants' map scores and incorrect propositional statements presented the development and learning difficulties of geospatial concept knowledge. Although participants' scores evaluated by the structural did not change significantly over a semester, there was a significant difference in scores evaluated by the relational. There was a significant difference between the scores of maps created in the first session and the scores of maps revised in the second and third sessions. The follow-up analysis suggested there was a significant difference between the scores of maps created in the first session and the scores of maps revised in the second session. The analysis of the second research question described that half of the twelve participants regarded scale as the cause of distortion. The analysis of the third research question showed there was a significant difference between the scores of the three complexity levels. The follow-up analysis suggested there was a significant difference between the scores of the primitive and simple concept level and the scores of the complicated and complex concept level.

CHAPTER V

DISCUSSION AND CONCLUSIONS

As an aid to the reader, this final chapter reiterates the research problem and outlines the major methods used in the study. After the introductory section, the major sections of this chapter summarize the results and discuss their implications.

Introduction

The research communities of GIS education and spatial thinking are increasingly aware that GIS is an effective education tool for reinforcing students' spatial thinking proficiency (Goodchild 2006, Kerski 2008b, National Research Council 2006). However, it is still unclear whether GIS education is effective for improving students' knowledge in relation to spatial concepts, which are the basis of spatial thinking (Golledge 2002). Although spatial concepts critically affect spatial thinking with GIS, there is little empirical research that examines if college-level students can develop their geospatial concept knowledge through an education in GIS and what difficulties they encounter when learning geospatial concepts. This study had the following three research questions: 1) what differences exist between students' understandings of spatial concepts at the beginning, middle, and end of an introductory-level GIS course; 2) what geospatial misconceptions students may possess while taking an introductory-level GIS course; and 3) which geospatial concepts are easy or hard for undergraduate university students to understand.

As stated in Chapter III, the methodology was based on a single-group time series design. The researcher asked participants to attend a training session and three experiment sessions in the beginning, middle, and end of a semester. In the training session, participants learned what a concept map is and how to create a concept map with concept mapping software. Each participant created a concept map about space in all three experiment sessions. In addition, these participants revised the concept maps they created in the previous session in the second and third sessions. The participants were Texas A&M University undergraduate students who were taking one of the two introductory-level GIS courses offered by the Department of Geography and the Department of Ecosystem Science and Management. After the researcher obtained sixty concept maps from twelve participants, he scored the maps and analyzed propositional statements described on the maps. The results of this study are suggestive and exploratory. The results may not be generalizable due to a small number of participants, but this limited sample size enabled the researcher to conduct a more in-depth analysis with a variety of concept map analysis methods.

Interpretation of Results in Research Question 1

For the first research question, the researcher scored sixty concept maps by two scoring schemes: structural and relational. The structural scoring scheme measures the degree of hierarchical complexity in each concept map; the relational scoring scheme evaluates the quality of interrelationships between concepts. The analyses of concept maps with the two scoring schemes showed different results.

The Structural Scores

The researcher statistically analyzed map scores evaluated by the structural scoring scheme to examine if there are any significant differences in the following four combinations: 1) maps created in the first session – maps created in the second session – maps created in the third session, 2) maps created in the first session – maps created in the second session – maps revised in the third session, 3) maps created in the first session – maps revised in the second session – maps created in the third session, and 4) maps created in the third session – maps revised in the second session – maps revised in the third session (See Table 18). There was no significant difference in these four combinations. This means the structural scores did not change significantly over the course of the semester.

One of the interpretations of this result is that the structural scoring scheme could not detect the development of participants' conceptual knowledge structure. Participants arranged spatial concepts assigned by the researcher even though they were advised to use only the concepts with which they were familiar. If they were allowed to use freely the concepts that came to their minds, the scores may have had more variation. This may have enabled the structural to scoring scheme detect participants' knowledge structure development. The structural scoring scheme weighted successive branchings, hierarchy, and valid crosslinks. However, these map components, which are strongly related to the hierarchical complexity of maps, had not dramatically increased in a single semester. This also prevented participants from obtaining higher scores.

Another possible interpretation is that a single semester is too short a period of time to detect the development of participants' conceptual knowledge structure. The development of cognitive structures may gradually progress over a longer period than a single semester, or radical structural changes did not occur in a single semester. Some modest and weak restructuring such as subsumption (Ausubel et al. 1986) and accretion (Rumelhart and Norman 1978) may have occurred in a semester; however, radical restructuring such as super ordinate learning (Ausubel et al. 1986) and restructuring (Rumelhart and Norman 1978) may not have enough time to develop. These possible factors may have hindered the improvement of map scores assessed by the structural.

The Relational Scores

Map scores evaluated by the relational scoring scheme were analyzed using the same statistical analysis method as the structural scoring scheme. The same four combinations as that of the structural scoring scheme were analyzed using a Friedman's ANOVA test to examine if there were any significant difference in those combinations (See Table 19). The results of this analysis showed that there was a significant difference in a combination composed of the concept maps originally created in the first session and the concept maps revised in the second and third sessions. The follow-up Wilcoxon signed-rank test of this combination indicated there was a significant change in a comparison between the maps originally created in the first session and the maps revised in the second session (See Table 20). In addition, the mean and median values of the scores of maps revised in the second session are larger than the values of the scores of maps created in the first session (See Table 15). This result implied that participants significantly improved their own original spatial maps in the second session.

Revision may have affected the increase in scores between the maps created in the first session and the maps revised in the second session. Revising maps may have been easier for participants than creating new maps, thus increasing their scores. However, this factor may be not the case because a comparison between the maps originally created in the second session and the maps revised in the third session did not show a significant change. The different results may imply that revision itself did not influence participants' concept mapping.

Considering the results of the relational score analysis, it could be said that the development of participants' conceptual knowledge mainly occurred between the first experiment session and the second experiment session. There may be two reasons why participants could improve their map scores in the first half of the semester: 1) participants became accustomed to making a concept map in the first half of the semester; 2) participants mainly learned concepts in the first half of the semester because most geospatial concepts were introduced in the lectures of the two introductory-level GIS courses in that period. Both of the courses focused on fundamental geospatial concepts in the first half of the semester. In the latter half of the semester, the instructors mainly emphasized geospatial concepts applied to spatial analysis. The relational scoring scheme is supposed to be sensitive to students' understandings of concepts covered in instruction (Rice et al. 1998, Rye and Rubba 2002). This advantage of the relational scoring scheme may have enabled the researcher to detect the development of students' conceptual knowledge.

Interpretation of Results in Research Question 2

The second research question was what geospatial misconceptions may exist among students who are taking an introductory-level GIS course. In the analysis of this research question, the researcher examined the incorrect propositional statements that were extracted from participants' concept maps to identify the misunderstandings of map projection, scale, and distortion. This section also examined if the misconceptions had disappeared in the course of a single semester.

The belief that scale may create distortion is a scientifically irrelevant misconception that must be removed for appropriate science learning. The results of this analysis indicated some participants had such misconceptions (See Table 25). Of twelve participants, four participants retained those misconceptions. They basically thought that scale was the cause of distortion, when, in reality, distortion should be related to map projection. Two other participants also thought that scale was the cause of distortion in the first session. However, they improved their misconceptions by the second and third session. They represented that the cause of distortion was due to map projection.

Some undergraduate students had misconceptions related to map projection, scale, and distortion. This result is supported by Downs and Liben's (1991) study. They suggested that understanding map projection is problematic for some students. The results of their study indicated that many college students failed to predict the shape of shadow projections of a simple form. If students have difficulty imagining how a simple object would be projected, it is small wonder that it is challenging for some undergraduate students to comprehend the intrinsic nature of a map projection: transforming the three-dimensional Earth to a two-dimensional flat surface. The mechanism of this transformation is sometimes illustrated by the following well-known explanatory diagram: a light bulb that is set in the center of a transparent globe projects a set of graticules onto the plane surface, the cylinder surface, and the cone surface (Dent, Torguson and Hodler 2009). This cognitively complicated transformation may baffle some university students and hamper them from understanding the concept of map projection.

The results implied that misconceptions in relation to distortion, map projection, and scale were difficult for some students to dislodge. Even when the two introductory-level GIS courses spent three or four weeks on map projection, four participants' misconceptions still persisted. In GEOG390, the concept of map projection was discussed in the second, third, and fourth weeks. In FRSC 461, the concept of map projection and coordinate systems were discussed in the third and fourth weeks. In GEOG390, a lab activity that mainly dealt with map projection and coordinate systems took place in the fourth week. In FRSC 461, a lab activity that mainly dealt with map projection and coordinate systems took place in the third week.

Even though the concept of map projection was emphasized by the instructors and in the GIS laboratories, it was difficult for some participants to understand the concept appropriately. It is basically challenging for students to change from their scientifically inappropriate knowledge to appropriate knowledge (Anderson and Smith 1987, Chi 2005). The results of this study also indicate that there may be scientifically inappropriate geospatial concept knowledge that undergraduate students have difficulty resolving.

The misconceptions that relate to the concepts of distortion, map projection, and scale may come from students' perceptual experiences of GIS operations that are involved with the change of map projection and scale. If a GIS user changes from large scale, typically for town-scale maps, to small scale, typically for world-scale maps, a distortion of the map would become conspicuous. However, the distortion was not clearly visible in large scale. This seeming occurrence of distortion may basically mislead a GIS user: the change of scale may create distortion. Even if a GIS user changes map projections on large-scale maps, the emergence of distortion would not become noticeable. This might make some GIS users misunderstand that the change of map projection does not cause distortion. These visually perplexing events may prevent GIS users from relating map projections to distortion. A function of GIS software may also be a visual cause of participants' misunderstandings. ArcGIS, which was the GIS software that students used in the two GIS courses, has a convenient function which enables users to automatically adjust the map projection of a map layer that is being added onto a map to the map projection of the other existing map layers. If a GIS user is conscious of the fact that a map projection of a newly added layer is different from that of existing layers, he or she may anticipate a geographic gap that is caused by the coexistence of different map projections. However, some users might dismiss problems due to map distortion because the software automatically adjusts a map projection and negates the influence by different map projections. The interpretation extracted from the analysis of participants' incorrect propositional statements meets McCloskey's (1984) assertion: perceptual experiences may cause misconceptions. Visually confusing display brought about by GIS software may also cause students' geospatial misconceptions.

Interpretation of Results for Research Question 3

The third research question was which geospatial concepts are easy or difficult for students to understand. The researcher calculated the concept-based scores of thirty geospatial concepts and categorized them into the following three complexity levels: the primitive and simple level, the difficult level, and the complicated and complex level. This categorization was based on an ontology established by Golledge and his students (Golledge et al. 2008, Golledge 1995, Marsh et al. 2007) (See Table 16). For the statistical analysis, the researcher examined if there was significant difference among the scores of the three complexity levels. The researcher also analyzed the scores of the twenty-eight concepts that did not include two outliers: the concept of coordinate and the concept of map projection.

The mean and median score values of the primitive and simple level, which was the simplest level among the three levels, were the highest; the mean and median score values of the complicated and complex level, which was the most difficult level among the three levels, were the lowest (See Table 17). The results of the Kruskal−Wallis test with the thirty geospatial concepts indicated that the scores were significantly different among the three complexity levels (See Table 26). The Kruskal−Wallis test without the two outliers yielded a lower p-value than that of the test with the full set. Concept-based scores were significantly different among the three different levels (See Table 27). The follow-up Mann−Whitney test with the thirty geospatial concepts indicated that the concept-based scores were significantly different in a comparison between the primitive and simple concept level and the complicated and complex concept level (See Table 28). The follow-up Mann−Whitney test without the two outliers yielded a lower p-value than that of the test with the full set. There was significant difference between the scores of the primitive and simple concept level and the complicated and complex concept level (See Table 29).

Considering the results of the statistical analyses, it can be said that, in general, college-level participants' comprehension of geospatial concepts matched Golledge's framework that was established based on the complexity of geospatial concepts. The results implied that participants' comprehension decreased as the complexity of a concept increased. This implication yielded two interpretations. The first interpretation is that college students tend to fail to understand higher order geospatial concepts compared to lower order concepts. The second implication is that there are different geospatial concept levels in terms of the complexity of concepts. Although the existing research (Battersby et al. 2006, Golledge et al. 2008, Marsh et al. 2007) suggested that the framework can be used in a K-12 system, the framework can also be used in a university introductory-level GIS course.

The results of the statistical analysis without the two outliers, which are the concepts of coordinate and map projection, showed more significant differences than the statistical analysis with a full set of concepts. The concept-based scores of coordinate and map projection were extraordinarily high in the difficult level and the complicated and complex level respectively. There is a possible reason why these concepts were outliers. The lecturers of GEOG390 and FRSC 461 spent two or three weeks in teaching these concepts. Time spent on these essential concepts was relatively longer than time on the other concepts. The reason why the scores of these two concepts are high may be due to an instruction effect. Considering this effect, it can be said that participants' comprehension of complicated and complex concepts may not have been as high if the two outlier concepts were not taught as intensively.

Implications

The results of this study have implications for teaching strategies. Concept maps can be used to evaluate students' conceptual development, to identify misconceptions, and to become acquainted with the difficulty level of concepts. Feedback from students' concept maps is constructive to the improvement of both students' learning and instructors' teaching.

The results implied that instructors may use concept maps to assess the development of students' conceptual knowledge. If students revise the concept maps they created themselves several weeks before, instructors would be able to identify differences between the two maps by comparing them. The differences may show how the hierarchical structures of concept maps have changed. If instructors notice the differences of propositional statements connecting two concepts, they could assess the degree to which students understand concepts covered in instruction. Furthermore, instructors could score concept maps by counting map components or examining the correctness of propositional statements. This time-series assessment may acquaint instructors with students' conceptual development.

The results also implied that instructors cannot assume uniform comprehension of concepts in students. The results of this study suggested that some students misunderstood the concepts of map projections and scale. They failed to relate map projection to distortion; instead, they believed that scale may create distortion. In terms of these concepts, representations brought about by GIS software may mislead students. Before students perform a lab activity that involves map projections, an instructor may emphasize that the use of appropriate map projection reduces distortion on a map, and the change of scale does not affect the existence of distortion. It is very challenging for some students to understand the mechanism of projecting round Earth on a flat paper. If an instructor dismisses a demonstration with a simple projection case, some students would not be able to appreciate the substance of map projection, which is the fact that distortion is inevitable when projecting Earth.

The third implication is that instructors may present simpler concepts before they teach more complicated concepts to effectively assist students learning the concepts. This study focused on a geospatial ontology introduced by Golledge and his students (Battersby et al. 2006, Golledge et al. 2008, Marsh et al. 2007); the results of their studies implied that the ontology is usable in recognizing what concepts are easy or hard for students to understand. According to the ontology, the concept of buffer belongs to the complicated level (See Table 3). This concept has some prerequisite concepts for students to learn. The possible concepts are location, distance, proximity, shape, area, and polygon. The ontology and the results of this study recommend that instructors confirm students are familiar with prerequisite simple concepts before they teach students complicated concepts.

Recommendations for GIS Instructors

The fundamental assertion of this study is that students should develop their spatial literacy in a GIS course that is grounded in a well-balanced emphasis of geospatial technologies and geospatial concepts (Goodchild 2006). What is demanded of GIS instructors now is to plan curriculum, assessment, and instruction to augment students' spatial concept knowledge and to implement such a plan in their classroom. As recommended for GIS instructors, this study introduces a unit of an introductory-level GIS course and articulates how GIS instructors use concept maps for teaching spatial concepts.

The unit for teaching spatial concepts has been developed based on the three components of learning expectation: an enduring understanding, required knowledge, and required skills. An enduring understanding expected of students is that spatial concepts enable GIS users to think about spatial phenomena more clearly and critically and communicate more efficiently and effectively about the outcomes of spatial inquiry and analysis. Regarding required knowledge, students learn the meanings of major spatial concepts that are necessary for discussing geographic phenomena. Those concepts might be cluster, connectivity, density, direction, distance, dispersion, distribution, lines, network, pattern, points, polygons, shape, size, and spatial relationships. For required skills, students are expected to attain competency of utilizing spatial concepts to identify, describe, manipulate, and analyze spatial relationships and to solve spatial problems. In order to have students attain the enduring understanding, required knowledge, and skills, three essential questions underpin this unit: 1) what spatial relationships can be identified by points, lines, and polygons; 2) what spatial knowledge can be obtained through spatial thinking; 3) how spatial concepts enhance people's spatial thinking through the use of GIS and maps.

The set of the enduring understanding, expected knowledge and skills, and the three essential questions guides a sequence of teaching and learning experiences for students (Table 30). In this sequence, three ideas are embedded: 1) instructors make spatial concepts explicit; 2) students apply spatial concepts to spatial problem solving; 3) students and instructors use concept maps as a learning tool and a teaching tool respectively. For the first idea, a novel statement, "GIS software solves spatial problems on behalf of GIS users," is presented to students. This will give students a motive for considering who leads spatial thinking through GIS. After instructors introduce spatial thinking, they introduce some major spatial concepts. The main aim of the first part is to have students understand that spatial thinking with a variety of spatial concepts enhances the quality of spatial inquiry through GIS.

Table 30. Sequence of teaching and learning for developing spatial concept knowledge

1	Present a statement, "GIS software solves spatial problems on behalf of GIS users," and discuss how GIS users think spatially while performing GIS analysis.
2	Introduce some major spatial concepts (e.g., cluster, connectivity, density, direction, distance, dispersion, distribution, lines, network, pattern, points, polygons, shape, size, and spatial relationships).
3	Allow students to work independently to perform hospital site selection analysis.
4	Have students map an optimum site for a new hospital.
5	Have students write a report about how they selected an optimum site.
6	Have students identify spatial concepts from their own report.
7	Conduct a group review to give and receive feedback on their analysis.
8	Have students think if some spatial concepts were not used for their analysis.
9	Introduce the concept map and discuss merits of spatially organizing concepts.
10	Allow students to work independently to develop a concept map about space.
11	Observe and coach students as they work on their concept mapping.
12	Have students evaluate their own and peers' concept maps using rubrics.

For the second idea, students consciously engage in spatial thinking while solving a spatial problem. This activity encourages students to apply spatial concepts to a site selection analysis, which is widely practiced in the public and private sectors and performed by GIS professionals (Milson and Curtis 2009). In this analysis, students will locate an optimum site for a new hospital in a city. A new hospital is best located at a place where three criteria are met: 1) a new hospital should service areas where existing hospitals do not; 2) a new hospital should serve as many patients as existing hospitals; 3) a new hospital should be accessible with minimal travel time for the targeted population. To solve this spatial problem, students need to manipulate and analyze spatial relationships that appear among the following five items of geographic features: possible new hospital site, existing hospitals, 1.5-mile buffer areas of existing hospitals, the dots that represent population distribution, and major roads (Figure 12). Students need to explore a variety of spatial concepts to identify the best location for the new hospital. For example, a student examines a cluster of population, connectivity and distances between residential areas and hospitals, and the network of major roads. As a product of this analysis, students write a report that describes their own spatial thinking for the analysis and justifies their site selections. The review of their own reports gives students an opportunity for reconsidering which spatial concepts they used and exchanging feedback with the other students.

A culminating performance embodies the third idea, which posits that the concept map is a tool for learning and teaching. At the beginning of this part, instructors introduce the concept map with particular emphasis on the characteristic that concept maps enable people to comprehend abstract relationships among concepts. After this introduction, students develop a concept map about space to exhibit their own understanding of the key spatial concepts that students should know. This gives them an opportunity of reflecting on which spatial concepts they clearly understand and reconsidering what each concept represents and how each spatial concept relates one another. While students are creating a concept map, instructors suggest making a concept map hierarchical, adding crosslinks between different branches and revising their own completed maps. Finally, students evaluate their own concept maps by referring to rubrics. Students would learn the diversity of concept maps and a variety of concept meanings by assessing their peers' concept maps. Instructors can make the concept map part of their teaching repertoire. Experiencing multiple different types of performances is effective for students to develop conceptual knowledge (Gregg and Sekeres 2006). It can be said that instructors can use concept maps as not only an assessment tool but also as a teaching tool.

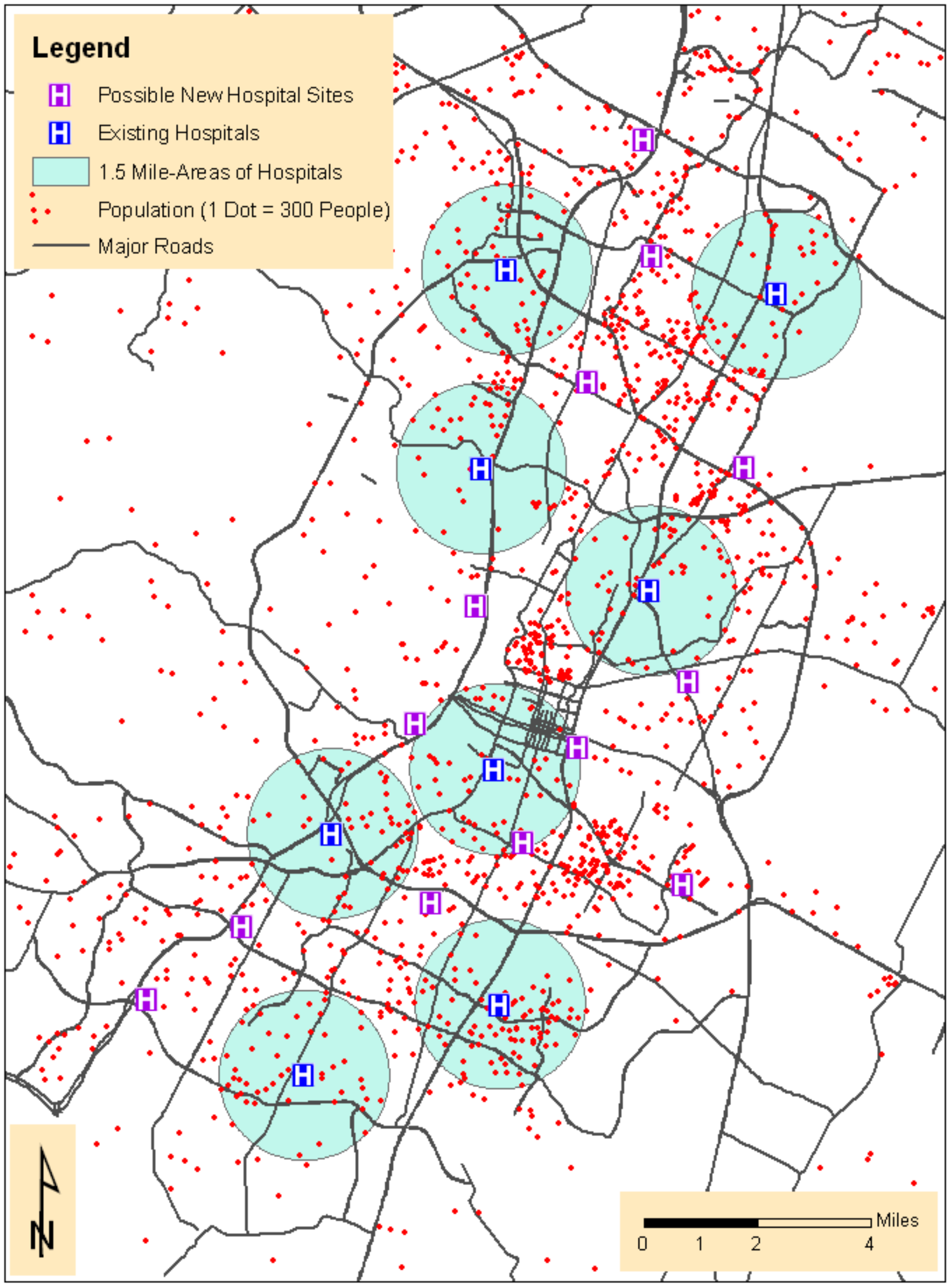

Figure 12. A map for hospital site selection analysis

Recommendations for Future Research

The results and analyses regarding the three research questions posed some recommendations for future research. The suggested future research could have three themes. The first theme is if and how instruction affects students' geospatial concept learning. The second theme is if and how students' spatial representations and reasoning improve as a consequence of the development of spatial concept knowledge. The third theme is what kinds of geospatial concepts are complicated or simple for students in various circumstances.

The first future research may examine the effect of instruction on students' geospatial concept knowledge. A researcher may conduct a multiple-group experiment including a control group and the groups who receive special instruction to assess the effectiveness of instruction on concept learning. In that study, a researcher may teach several student groups using different teaching methods to identify which method is the most effective for students' conceptual development. A researcher may also make the length of experiment periods longer to examine the long-term effects of instruction in spatial science courses.

The second future research may focus on the influence of conceptual development on students' spatial representations and reasoning. A researcher may compare students who appropriately understand the concept of map projection with students who do not in terms of their competency in spatial tasks that involve the concept. A researcher also may track students' conceptual development and the improvement of representation and reasoning competency simultaneously. A cause-and-effect relation among the three spatial thinking components should be explored in future research.

The third recommendation for future research is to explore further the complexity levels of geospatial concepts. Future research may adopt a wide variety of geospatial concepts and examine the degree to which students have difficulty learning. In addition, a researcher may focus on not only GIS courses but also other geography and environmental science courses. If the complexity of geospatial concepts is extensively probed in various settings, the results of the future research would strongly confirm which geospatial concepts should be taught before they teach a specific geospatial concept. This would be useful for the improvement of spatial science curriculum and pedagogy.

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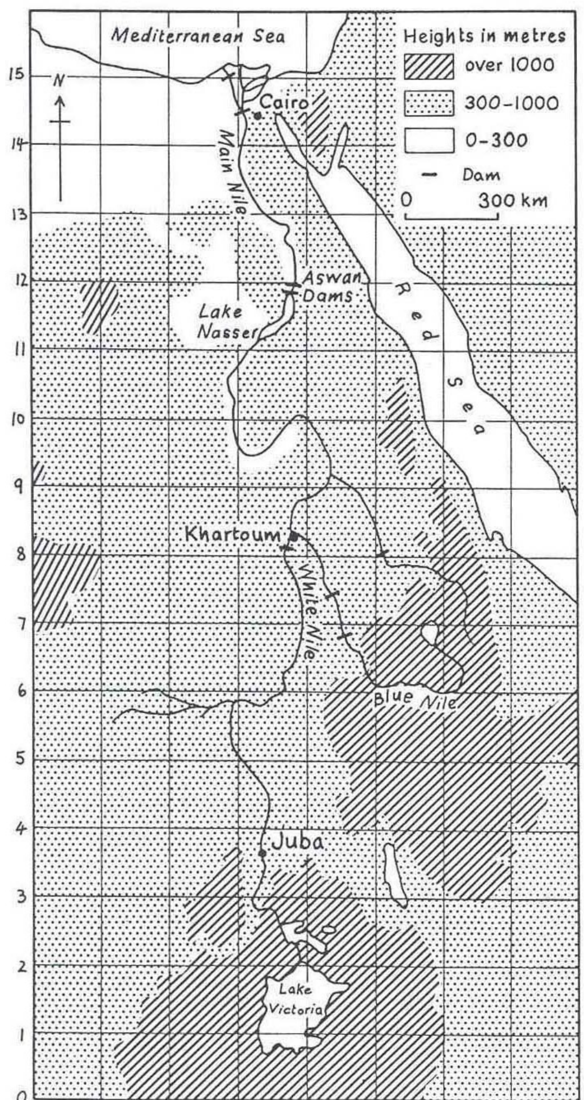
APPENDIX A

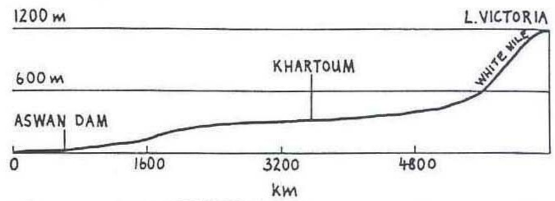
SELECTED QUESTIONS OF SPATIAL SKILLS TEST

The questions and figures reported in Appendix A are reprinted with permission from Effect of GIS Learning on Spatial Ability, Ph.D. dissertation, by Jong Won Lee, 2006, Texas A&M University, College Station.

Lee, J. 2006. Effect of GIS learning on spatial ability. PhD dissertation, Texas A&M University, College Station.

Direction: A group of young travelers is making a journey down the White Nile. They make notes as they travel. Below are three pages from their notebook. They are not in order. Based on information below, find the place each note indicates and write grid reference as (X, Y) format. (This direction was asked in the first experiment session. When participants were asked to perform this direction, an answer of the first question (4,9) was not indicated.)





Another river flows into this one. We are close to a large city. The height of the land is about 300 metres. Further upstream there was a dam.

Grid reference: (4 , 9)

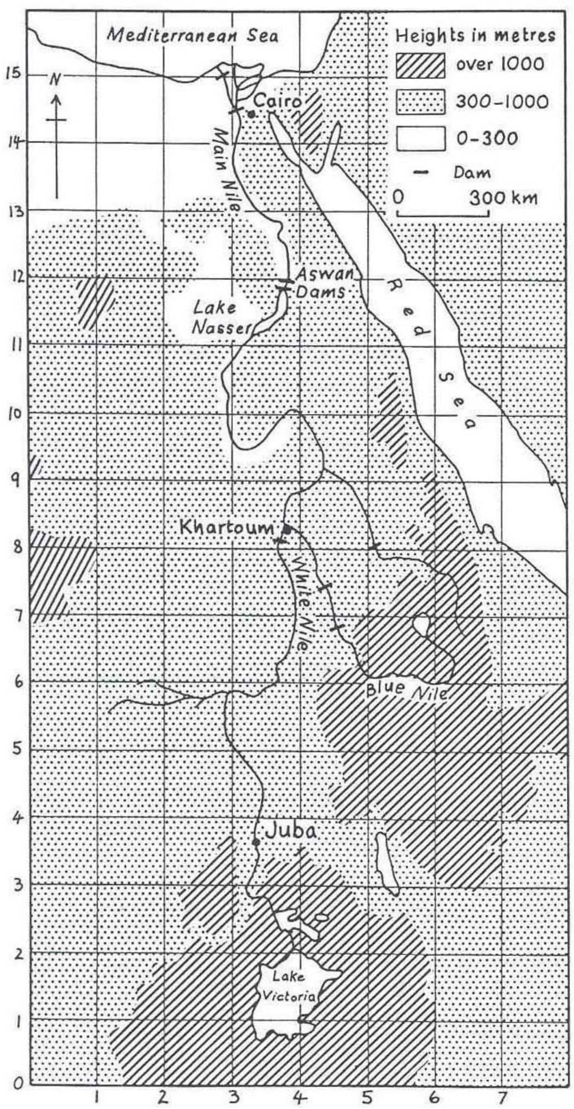
The river sweeps in a large bend to the west. There are fertile fields on either side. Up stream was a town sited where another river joined this one.

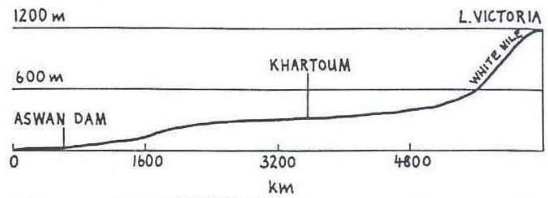
Grid reference: (,)

We are high up, probably about 1200 metres above sea level. We are close to a huge lake. North of us there is another large lake. The river flows quickly here.

Grid reference: (,)

Direction: A group of young travelers is making a journey down the White Nile. They make notes as they travel. Below are three pages from their notebook. They are not in order. Based on information below, find the place each note indicates and write grid reference as (X, Y) format. (This direction was asked in the third experiment session. When participants were asked to perform this direction, an answer of the first question (4,9) was not indicated.)





Another river flows into this one. We are close to a large city. The height of the land is about 300 metres. Further upstream there was a dam.

Grid reference: (4 , 9)

The river flows very slowly here. We are approaching a very big delta. A large city lies to the east. Yet another dam lies ahead.

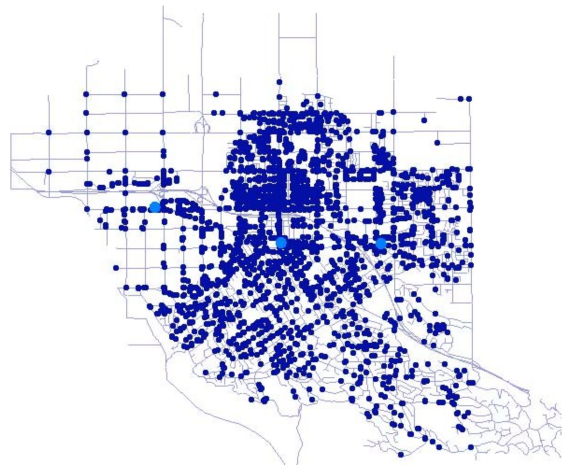
Grid reference: (,)

Here there are two dams close together, down stream of a long, narrow lake. No other rivers have joined this one for many kilometres.

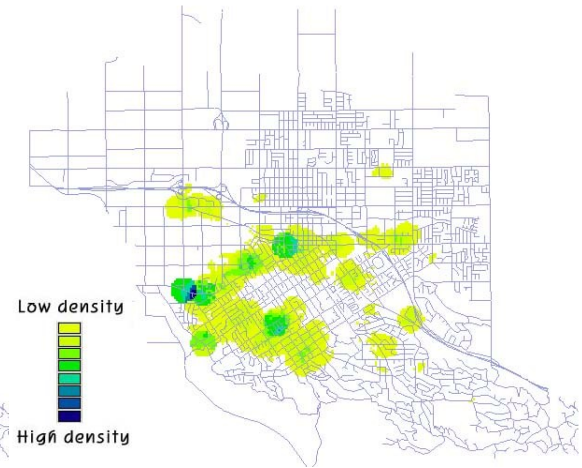
Grid reference: (,)

Direction: Find a new best site for a coffee shop based on the following conditions. (This direction was asked in the first experiment session.)

- Possible site for a new store should be more than 1 mile from any existing stores. If any stores are closer than 1 mile, they may compete with each other for customers.
- Possible site for a new store should be easy for potential customers to access. 'Customer density' shows the density of coffee drinkers who have visited the three stores over the last year.

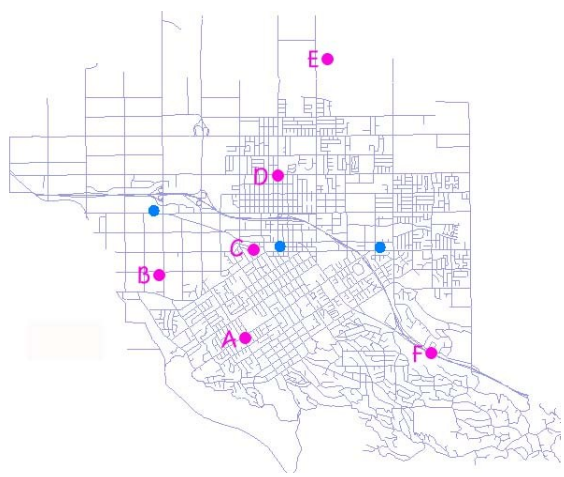


Population distribution



Customer Density

Distance from existing stores

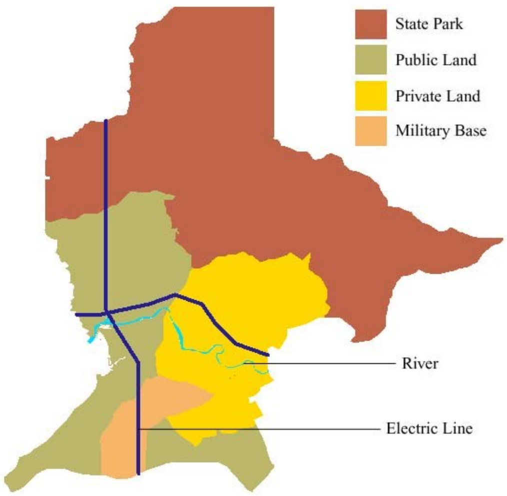


Potential store location

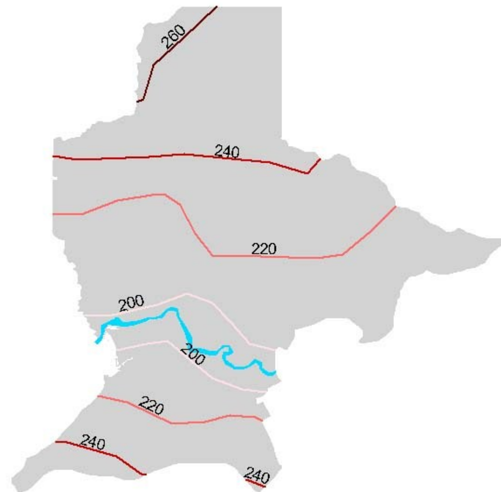
[5] Mark (√) on the best site for a potential coffee shop on the map above.

Direction: Find the best location for a flood management facility based on the following conditions. (This direction was asked in the third experiment session.)

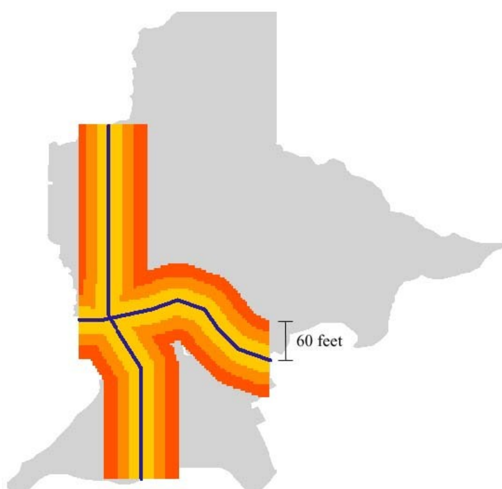
- Possible site for a flood management facility should be within 60 ft of an existing electric line.
- Possible site for a flood management facility should be located less than 220 elevation level.
- Possible site for a flood management facility should be located in State Park or Public Land.



Land use



Elevation (feet)



60 feet from electric line

Potential facility location

[5] Mark [√] on the best site for the flood management facility on the map above.

APPENDIX B

A PROPOSITIONAL PAIR MATRIX

CONCEPTS	arrangements	association	boundary	buffer	cluster
arrangements	NA	Partially Correct	Partially Correct	Partially Correct	Incorrect
association	Partially Correct	NA	Partially Correct	Partially Correct	Partially Correct
boundary	Partially Correct	Partially Correct	NA	Partially Correct	Incorrect
buffer	Partially Correct	Partially Correct	Partially Correct	NA	Incorrect
cluster	Incorrect	Partially Correct	Incorrect	Incorrect	NA
coordinate	Partially Correct	Incorrect	Partially Correct	Partially Correct	Partially Correct
density	Incorrect	Incorrect	Incorrect	Incorrect	Correct
diffusion	Incorrect	Partially Correct	Incorrect	Incorrect	Partially Correct
direction	Partially Correct	Incorrect	Incorrect	Incorrect	Incorrect
dispersion	Incorrect	Partially Correct	Incorrect	Incorrect	Correct
distance	Partially Correct	Incorrect	Incorrect	Correct	Incorrect
distortion	Partially Correct	Partially Correct	Partially Correct	Partially Correct	Partially Correct
distribution	Correct	Correct	Incorrect	Incorrect	Correct
line	Partially Correct	Partially Correct	Correct	Partially Correct	Partially Correct
linkage	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect
location	Correct	Partially Correct	Correct	Partially Correct	Partially Correct
map projection	Partially Correct	Partially Correct	Partially Correct	Partially Correct	Partially Correct
network	Incorrect	Correct	Incorrect	Incorrect	Incorrect
overlay	Incorrect	Partially Correct	Correct	Correct	Incorrect
pattern	Incorrect	Correct	Incorrect	Incorrect	Incorrect
point	Partially Correct	Partially Correct	Incorrect	Partially Correct	Partially Correct
polygon	Partially Correct	Partially Correct	Partially Correct	Correct	Partially Correct
proximity	Partially Correct	Incorrect	Incorrect	Correct	Partially Correct
scale	Correct	Incorrect	Partially Correct	Partially Correct	Partially Correct
shape	Correct	Partially Correct	Partially Correct	Partially Correct	Partially Correct
size	Incorrect	Incorrect	Partially Correct	Partially Correct	Incorrect
spatial relationship	Correct	Correct	Partially Correct	Partially Correct	Partially Correct
three dimensions	Partially Correct	Partially Correct	Partially Correct	Partially Correct	Partially Correct
topology	Incorrect	Incorrect	Correct	Partially Correct	Incorrect
two dimensions	Partially Correct	Partially Correct	Partially Correct	Partially Correct	Partially Correct

CONCEPTS	coordinate	density	diffusion	direction	dispersion
arrangements	Partially Correct	Incorrect	Incorrect	Partially Correct	Incorrect
association	Incorrect	Incorrect	Partially Correct	Incorrect	Partially Correct
boundary	Partially Correct	Incorrect	Incorrect	Incorrect	Incorrect
buffer	Partially Correct	Incorrect	Incorrect	Incorrect	Incorrect
cluster	Partially Correct	Correct	Partially Correct	Incorrect	Correct
coordinate	NA	Partially Correct	Partially Correct	Correct	Partially Correct
density	Partially Correct	NA	Incorrect	Incorrect	Correct
diffusion	Partially Correct	Incorrect	NA	Incorrect	Partially Correct
direction	Correct	Incorrect	Incorrect	NA	Incorrect
dispersion	Partially Correct	Correct	Partially Correct	Incorrect	NA
distance	Correct	Incorrect	Incorrect	Incorrect	Correct
distortion	Partially Correct	Incorrect	Partially Correct	Correct	Partially Correct
distribution	Partially Correct	Correct	Correct	Incorrect	Correct
line	Correct	Incorrect	Incorrect	Partially Correct	Incorrect
linkage	Partially Correct	Incorrect	Incorrect	Incorrect	Partially Correct
location	Correct	Partially Correct	Partially Correct	Correct	Partially Correct
map projection	Partially Correct	Incorrect	Partially Correct	Correct	Partially Correct
network	Partially Correct	Incorrect	Partially Correct	Incorrect	Incorrect
overlay	Correct	Incorrect	Incorrect	Incorrect	Incorrect
pattern	Partially Correct	Incorrect	Partially Correct	Incorrect	Correct
point	Correct	Incorrect	Partially Correct	Incorrect	Partially Correct
polygon	Correct	Incorrect	Incorrect	Incorrect	Incorrect
proximity	Partially Correct	Incorrect	Incorrect	Incorrect	Partially Correct
scale	Correct	Incorrect	Partially Correct	Incorrect	Partially Correct
shape	Correct	Incorrect	Partially Correct	Incorrect	Partially Correct
size	Partially Correct	Incorrect	Incorrect	Incorrect	Incorrect
spatial relationship	Partially Correct	Partially Correct	Partially Correct	Partially Correct	Correct
three dimensions	Correct	Incorrect	Partially Correct	Partially Correct	Partially Correct
topology	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect
two dimensions	Correct	Incorrect	Partially Correct	Partially Correct	Partially Correct

CONCEPTS	distance	distortion	distribution	line	linkage
arrangements	Partially Correct	Partially Correct	Correct	Partially Correct	Incorrect
association	Incorrect	Partially Correct	Correct	Partially Correct	Incorrect
boundary	Incorrect	Partially Correct	Incorrect	Correct	Incorrect
buffer	Correct	Partially Correct	Incorrect	Partially Correct	Incorrect
cluster	Incorrect	Partially Correct	Correct	Partially Correct	Incorrect
coordinate	Correct	Partially Correct	Partially Correct	Correct	Partially Correct
density	Incorrect	Incorrect	Correct	Incorrect	Incorrect
diffusion	Incorrect	Partially Correct	Correct	Incorrect	Incorrect
direction	Incorrect	Correct	Incorrect	Partially Correct	Incorrect
dispersion	Correct	Partially Correct	Correct	Incorrect	Partially Correct
distance	NA	Correct	Partially Correct	Correct	Partially Correct
distortion	Correct	NA	Partially Correct	Partially Correct	Partially Correct
distribution	Partially Correct	Partially Correct	NA	Partially Correct	Incorrect
line	Correct	Partially Correct	Partially Correct	NA	Correct
linkage	Partially Correct	Partially Correct	Incorrect	Correct	NA
location	Correct	Partially Correct	Correct	Partially Correct	Partially Correct
map projection	Correct	Correct	Partially Correct	Partially Correct	Partially Correct
network	Partially Correct	Partially Correct	Partially Correct	Correct	Correct
overlay	Incorrect	Incorrect	Incorrect	Partially Correct	Incorrect
pattern	Partially Correct	Partially Correct	Correct	Partially Correct	Incorrect
point	Correct	Partially Correct	Partially Correct	Incorrect	Correct
polygon	Incorrect	Partially Correct	Partially Correct	Partially Correct	Incorrect
proximity	Correct	Incorrect	Partially Correct	Partially Correct	Incorrect
scale	Correct	Incorrect	Partially Correct	Partially Correct	Partially Correct
shape	Incorrect	Correct	Partially Correct	Correct	Partially Correct
size	Incorrect	Partially Correct	Incorrect	Partially Correct	Incorrect
spatial relationship	Partially Correct	Partially Correct	Correct	Partially Correct	Partially Correct
three dimensions	Partially Correct	Incorrect	Partially Correct	Partially Correct	Partially Correct
topology	Incorrect	Correct	Incorrect	Partially Correct	Incorrect
two dimensions	Partially Correct	Correct	Partially Correct	Partially Correct	Partially Correct

CONCEPTS	location	map projection	network	overlay	pattern
arrangements	Correct	Partially Correct	Incorrect	Incorrect	Incorrect
association	Incorrect	Partially Correct	Correct	Partially Correct	Correct
boundary	Correct	Partially Correct	Incorrect	Correct	Incorrect
buffer	Partially Correct	Partially Correct	Incorrect	Correct	Incorrect
cluster	Partially Correct	Partially Correct	Incorrect	Incorrect	Incorrect
coordinate	Correct	Partially Correct	Partially Correct	Correct	Partially Correct
density	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect
diffusion	Partially Correct	Partially Correct	Partially Correct	Incorrect	Partially Correct
direction	Correct	Correct	Incorrect	Incorrect	Incorrect
dispersion	Partially Correct	Partially Correct	Incorrect	Incorrect	Correct
distance	Correct	Correct	Partially Correct	Incorrect	Partially Correct
distortion	Partially Correct	Correct	Partially Correct	Incorrect	Partially Correct
distribution	Correct	Partially Correct	Partially Correct	Incorrect	Correct
line	Partially Correct	Partially Correct	Correct	Partially Correct	Partially Correct
linkage	Partially Correct	Partially Correct	Correct	Incorrect	Incorrect
location	NA	Partially Correct	Correct	Partially Correct	Partially Correct
map projection	Partially Correct	NA	Partially Correct	Incorrect	Partially Correct
network	Correct	Partially Correct	NA	Incorrect	Incorrect
overlay	Incorrect	Incorrect	Incorrect	NA	Incorrect
pattern	Partially Correct	Partially Correct	Incorrect	Incorrect	NA
point	Correct	Partially Correct	Partially Correct	Incorrect	Partially Correct
polygon	Partially Correct	Partially Correct	Incorrect	Partially Correct	Partially Correct
proximity	Partially Correct	Partially Correct	Incorrect	Incorrect	Incorrect
scale	Correct	Incorrect	Partially Correct	Incorrect	Correct
shape	Partially Correct	Correct	Incorrect	Correct	Incorrect
size	Incorrect	Partially Correct	Incorrect	Incorrect	Incorrect
spatial relationship	Partially Correct	Partially Correct	Correct	Correct	Partially Correct
three dimensions	Partially Correct	Correct	Partially Correct	Partially Correct	Partially Correct
topology	Incorrect	Correct	Partially Correct	Incorrect	Incorrect
two dimensions	Partially Correct	Correct	Partially Correct	Partially Correct	Partially Correct

CONCEPTS	point	polygon	proximity	scale	shape
arrangements	Partially Correct	Partially Correct	Partially Correct	Correct	Correct
association	Incorrect	Partially Correct	Incorrect	Incorrect	Partially Correct
boundary	Incorrect	Partially Correct	Incorrect	Partially Correct	Partially Correct
buffer	Partially Correct	Correct	Correct	Partially Correct	Partially Correct
cluster	Partially Correct	Partially Correct	Partially Correct	Partially Correct	Partially Correct
coordinate	Correct	Correct	Partially Correct	Correct	Correct
density	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect
diffusion	Partially Correct	Incorrect	Incorrect	Partially Correct	Partially Correct
direction	Incorrect	Incorrect	Incorrect	Incorrect	Incorrect
dispersion	Partially Correct	Incorrect	Partially Correct	Partially Correct	Partially Correct
distance	Correct	Incorrect	Correct	Correct	Incorrect
distortion	Partially Correct	Partially Correct	Partially Correct	Incorrect	Correct
distribution	Partially Correct	Partially Correct	Partially Correct	Partially Correct	Incorrect
line	Incorrect	Partially Correct	Partially Correct	Partially Correct	Correct
linkage	Correct	Incorrect	Incorrect	Partially Correct	Incorrect
location	Correct	Partially Correct	Partially Correct	Correct	Incorrect
map projection	Partially Correct	Partially Correct	Partially Correct	Incorrect	Correct
network	Partially Correct	Incorrect	Incorrect	Partially Correct	Incorrect
overlay	Incorrect	Partially Correct	Incorrect	Incorrect	Correct
pattern	Partially Correct	Partially Correct	Incorrect	Correct	Incorrect
point	NA	Incorrect	Partially Correct	Partially Correct	Correct
polygon	Incorrect	NA	Partially Correct	Partially Correct	Correct
proximity	Partially Correct	Partially Correct	NA	Partially Correct	Incorrect
scale	Partially Correct	Partially Correct	Partially Correct	NA	Correct
shape	Correct	Correct	Partially Correct	Correct	NA
size	Incorrect	Correct	Incorrect	Incorrect	Correct
spatial relationship	Partially Correct	Partially Correct	Correct	Incorrect	Correct
three dimensions	Partially Correct	Partially Correct	Partially Correct	Correct	Correct
topology	Incorrect	Partially Correct	Incorrect	Incorrect	Correct
two dimensions	Partially Correct	Partially Correct	Partially Correct	Correct	Correct
CONCEPTS	size	spatial relationship	three dimensions	topology	two dimensions
arrangements	Incorrect	Correct	Partially Correct	Incorrect	Partially Correct
association	Incorrect	Correct	Partially Correct	Incorrect	Partially Correct
boundary	Partially Correct	Partially Correct	Partially Correct	Correct	Partially Correct
buffer	Partially Correct	Partially Correct	Partially Correct	Partially Correct	Partially Correct
cluster	Incorrect	Partially Correct	Partially Correct	Incorrect	Partially Correct
coordinate	Partially Correct	Partially Correct	Correct	Incorrect	Correct
density	Incorrect	Partially Correct	Incorrect	Incorrect	Incorrect
diffusion	Incorrect	Partially Correct	Partially Correct	Incorrect	Partially Correct
direction	Incorrect	Partially Correct	Partially Correct	Incorrect	Partially Correct
dispersion	Incorrect	Correct	Partially Correct	Incorrect	Partially Correct
distance	Incorrect	Partially Correct	Partially Correct	Incorrect	Partially Correct
distortion	Partially Correct	Partially Correct	Incorrect	Correct	Correct
distribution	Incorrect	Correct	Partially Correct	Incorrect	Partially Correct
line	Partially Correct	Partially Correct	Partially Correct	Partially Correct	Partially Correct
linkage	Incorrect	Partially Correct	Partially Correct	Incorrect	Partially Correct
location	Incorrect	Partially Correct	Partially Correct	Incorrect	Partially Correct
map projection	Partially Correct	Partially Correct	Correct	Correct	Correct
network	Incorrect	Correct	Partially Correct	Partially Correct	Partially Correct
overlay	Incorrect	Correct	Partially Correct	Incorrect	Partially Correct
pattern	Incorrect	Partially Correct	Partially Correct	Incorrect	Partially Correct
point	Incorrect	Partially Correct	Partially Correct	Incorrect	Partially Correct
polygon	Correct	Partially Correct	Partially Correct	Partially Correct	Partially Correct
proximity	Incorrect	Correct	Partially Correct	Incorrect	Partially Correct
scale	Incorrect	Partially Correct	Correct	Incorrect	Correct
shape	Correct	Correct	Correct	Correct	Correct
size	NA	Incorrect	Correct	Incorrect	Correct
spatial relationship	Incorrect	NA	Partially Correct	Correct	Partially Correct
three dimensions	Partially Correct	Partially Correct	NA	Incorrect	Correct
topology	Incorrect	Correct	Incorrect	NA	Incorrect
two dimensions	Partially Correct	Partially Correct	Correct	Incorrect	NA

APPENDIX C

A CORRECT PROPOSITIONAL STATEMENT INVENTORY

CONCEPTS	PROPOSITIONAL STATEMENT	CONCEPTS
arrangements	sometimes includes	distribution
	are only defined with	location
	are not apparently affected with	scale
	are defined in terms of	shape
	can be used for describing	spatial relationship
association	tells about two or more similar sets of	distribution
	tells about two or more similar sets of	network
	tells about two or more similar sets of	pattern
	can be used for describing	spatial relationship
boundary	is a real or imagined dividing	line
	is necessary to delineate a region around	location
	is superimposed in	overlay
	has arrtibute for	topology
buffer	is superimposed in	overlay
	can be represented with	polygon
	is useful for analyzing	proximity
cluster	demonstrates a high	density
	can be explained with	dispersion
	demonstrates a type of	distribution
coordinate	provides a	direction
	is used for calculating	distance
	can be used for defining	line
	tells numerically exact	location
	is necessary for	overlay
	can represent a	point
	is necessary for depicting	polygon
	always involves	scale
	numerically represents	shape
	is built in	three dimensions
	is built in	two dimensions
density	is a measure of	cluster
	can be used for explaining	dispersion
	a measure of the number of frequency in a set of	distribution
diffusion	explains spread processes and	distribution
direction	can be calculated with	coordinate
	can be misrepresented with	distortion
	is often necessary for describing	location
	can be distorted with	map projection
dispersion	suggests explanation for	cluster
	is closely related to	density
	can be used for describing	distribution
	suggests explanations for	pattern
	can be used for describing	spatial relationship
distance	is necessary for defining	buffer
	can be calculated with	coordinate
	can be used for explaining	dispersion
	can be misrepresented with	distortion
	is determined along	line
	is often necessary for describing	location
	can be distorted with	map projection

CONCEPTS	PROPOSITIONAL STATEMENT	CONCEPTS
distance	can be used to tell about	proximity
	can be used for calculating	scale
distortion	causes the misrepresentation of	direction
	causes the misrepresentation of	distance
	is caused by the use of	map projection
	is the misrepresentation of	shape
	does not change	topology
	is the misrepresentaion on a map in	two dimensions
distribution	always includes	arrangements
	can be referred to identify	association
	with convergent is	cluster
	can be measured with	density
	is sometimes a spread result of	diffusion
	can be described with	dispersion
	tells about the magnitude or frequency of	location
	can be interpreted with regular	pattern
	can be used for describing	spatial relationship
line	is a real or imagined dividing geometry for	boundary
	is defined by a connected series of	coordinate
	tells	distance
	can represent	linkage
	can represent	network
	is a long and skinny type of	shape
linkage	is composed of	line
	composes	network
	tells the relationship connected with two or more	point
location	can be relatively shown in	arrangements
	can be used for delineating a	boundary
	can be exactly described with	coordinate
	can be described with	direction
	can be described with	distance
	can be a component of	distribution
	can be conncted along	network
	can usually be represented with	point
	is apparently affected with	scale
map projection	distorts	direction
	distorts	distance
	causes	distortion
	distorts	shape
	transforms	three dimensions
	cannot change	topology
	visualizes in	two dimensions
network	can be referred to identify	association
	involves movement and flow along	line
	is composed of	linkage
	is a set of lines that connect two or more	location
	can be used for describing	spatial relationship
overlay	shows spatial relationship by	boundary
	shows spatial relationship between	buffer
	manipulates	coordinate

CONCEPTS	PROPOSITIONAL STATEMENT	CONCEPTS
overlay	examines relationship between	shape
	examines	spatial relationship
pattern	can be referred to identify	association
	can be explained with	dispersion
	is a regularly repeated form of	distribution
	is not apparently affected with	scale
point	is defined by	coordinate
	can be referred for	linkage
	can have an attribute about a	location
	is a dot type of	shape
polygon	is a geometry of	buffer
	is defined by a connected sequence of	coordinate
	is a closed type of	shape
	has a possibility of having an attribute of	size
proximity	can be analyzed with	buffer
	is the state of being near entities in	distance
	can be used for describing	spatial relationship
scale	does not affect	arrangements
	can be calculated with	coordinate
	is the ratio between two types of	distance
	affects the representation of	location
	does not affect	pattern
	affects the representation of	shape
	can be defined in	three dimensions
	can be defined in	two dimensions
shape	can be relatively shown in	arrangements
	can numerically be recorded on	coordinate
	can be misrepresented with	distortion
	is used for generalizing geographic phenomena with	line
	can be distorted with	map projection
	is superimposed in	overlay
	is used for generalizing geographic phenomena with	point
	is used for generalizing geographic phenomena with	polygon
	is apparently affected with	scale
	has a possibility of having an attribute of	size
	can establish	spatial relationship
	can be shown in	three dimensions
	has a possibility of having an attribute of	topology
	can be shown in	two dimensions
size	can be an attribute of	polygon
	can be represented with	shape
	can be shown in	three dimensions
	can be shown in	two dimensions
spatial relationship	can be referred to identify	arrangements
	can be analyzed in terms of	association
	can be referred to identify	dispersion
	can be referred to identify	distribution
	explains movement along	network
	can be manipulated by	overlay
	can be referred to identify	proximity

CONCEPTS	PROPOSITIONAL STATEMENT	CONCEPTS
spatial relationship	tells the way relationship among	shape
	can be referred to identify	topology
three dimensions	are built with	coordinate
	can be transformed with	map projection
	can be used to define	scale
	is one of forms for representing	shape
	can be transformed to	two dimensions
topology	is an attribute of	boundary
	is unchanged with	distortion
	never be influenced by	map projection
	is an attribute of	shape
	can be used for describing	spatial relationship
two dimensions	are built with	coordinate
	can be misrepresented with	distortion
	is transformed with	map projection
	can be used to define	scale
	is one of forms for representing	shape
	can be transformed from	three dimensions

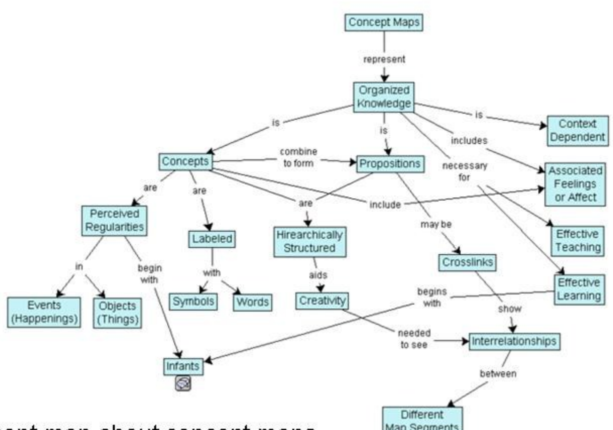
APPENDIX D

CONCEPT MAPPING TRAINING SLIDES

Training Session

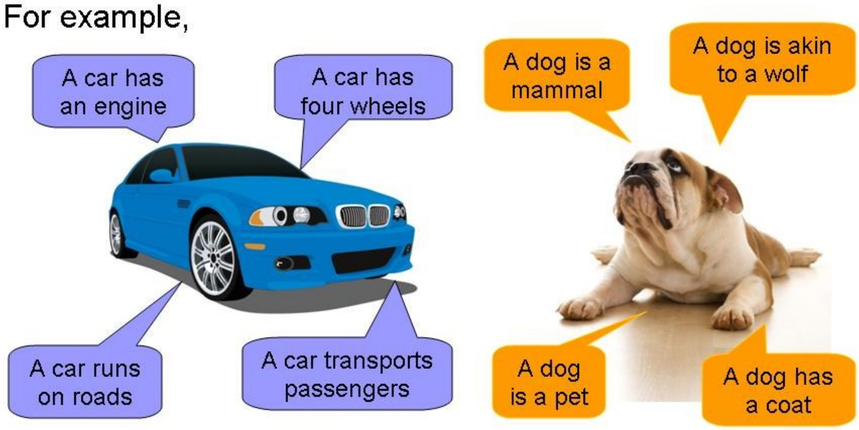
The Effect of GIS Learning on Knowledge Restructuring and Conceptual Change Related to Spatial Concepts

A **concept map** is a diagram showing the relationships among concepts. Concept maps are intended to represent meaningful relationships between concepts in the form of propositions.



A concept map about concept maps

Concepts describe the characteristics and regularities of objects such as "car" and "dog." You are familiar with concepts about "car" and "dog." What do you think of "car" and "dog?"
For example,

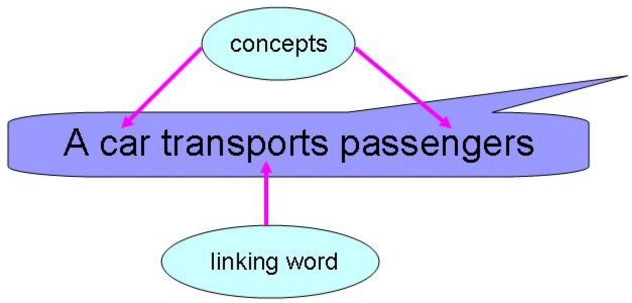


If you think of a car, you might think " a car transports passengers." If you think of a dog, you might think " a dog is a mammal." These two sentences describe the regularities of "car" and "dog" respectively. In addition, "passengers" and "a mammal" are also concepts. Both "passenger" and "mammal" are used to describe the higher-ordered concepts, which are "car" and "dog." Considering the grammatical aspect of these concepts, you recognize concepts are represented with common nouns.

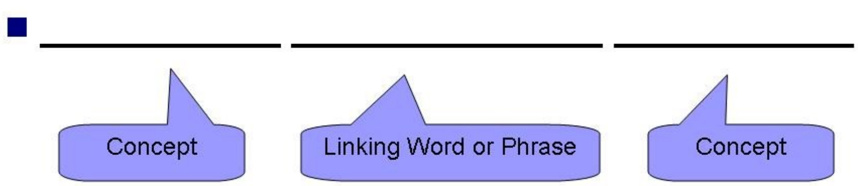
A car transports passengers

A dog is a mammal

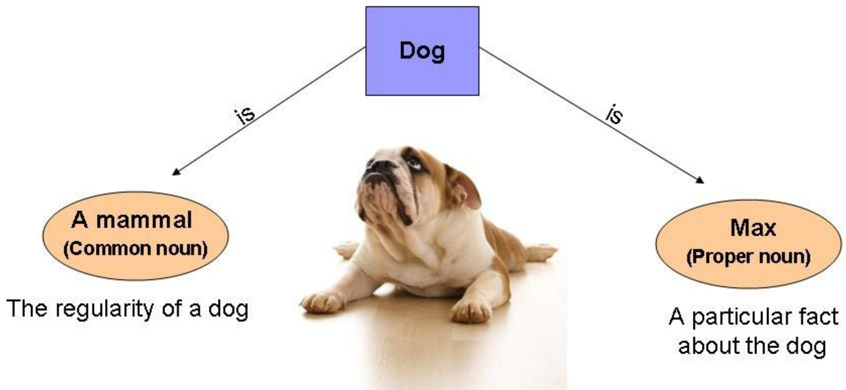
"Car," "passenger," "dog," and "mammal" are concepts. Then, what are "transports" and "is?" Verbs such as "is," "are," and "do" are not concept words but rather linking words. The relationship between concepts is also articulated in linking phrases, e.g., "gives rise to", "results in", "is required by," or "contributes to". A set of two concepts connected with a linking word or phrase is called a proposition.



Now, let's make a proposition by yourself. The concept words you can use are university, students, professor, and football. Select the two concepts from these four concepts. Put the selected concepts in the first and third blanks, and then put either your own linking word or phrase.



Concepts are represented with common nouns. On the other hand, proper nouns are not concept words but rather names of specific people, places, and objects. Proper nouns cannot describe regularities of objects but rather do describe particular facts. For example, "the dog is Max" which does not describe the regularity of a dog. On the other hand, "a dog is a pet" which describes the regularity of a dog.

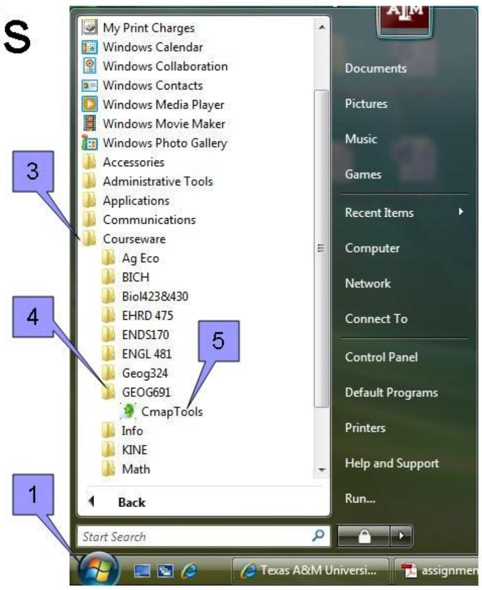


Save Cmap Files

- You have learned about concept maps. Now, let's make a concept map about Earth step by step.
- On your desktop save the following two Cmap files: Earth.cmap and Water.cmap
- The two Cmap files are attached on the email the experimenter sent.

Start CmapTools

1. Click the Windows Start button.
2. Click “All Programs.”
3. Click “Courseware.”
4. Click “GEOG691.”
5. Click “CmapTools.”
6. It may take few minutes to start.

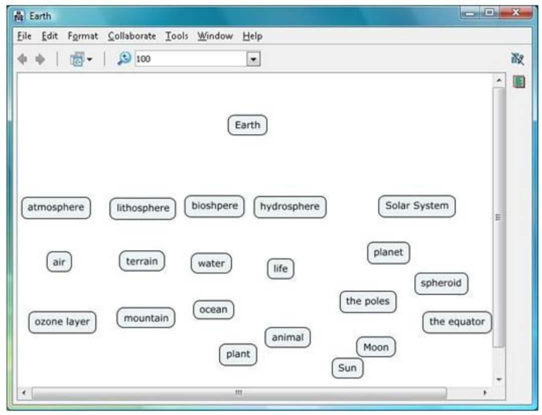


Open Cmap File

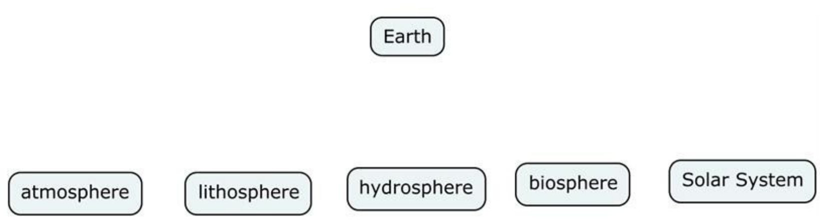
1. The CmapTools window pops up.
2. Drag the icon of “Earth.cmap” to the CmapTools window.
3. The Edit Resource Properties window pops up.
4. Click the OK button.
5. The “Earth” icon has appeared in the CmapTools window.
6. Double-click the “Earth” icon.

Make a Concept Map of "Earth"

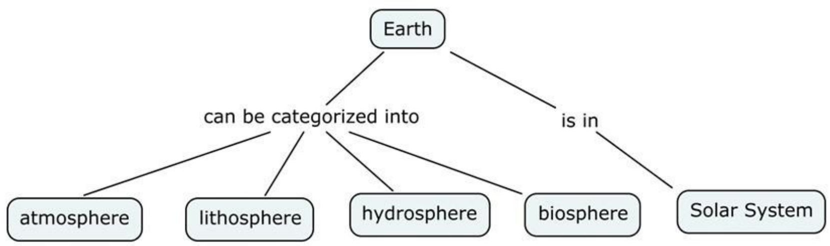
1. The "Earth" concept map window pops up.
2. Notice the concept map window has the following assigned words: atmosphere, lithosphere, air, hydrosphere, biosphere, the Sun, the Moon, planet, the Solar System, life, ozone layer, ocean, water, spheroid, the equator, the poles, plant, animal, and mountain.
3. You are just about to organize these words and connect them with links.



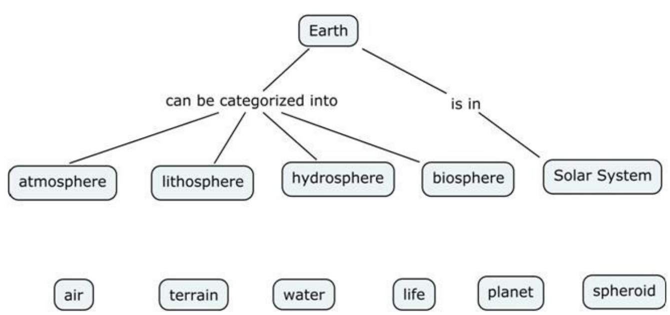
4. The assigned words are needed to be classified into the following three categories: the most inclusive concepts, intermediate inclusive concepts, and the least inclusive concepts.
5. All of the assigned words have already been classified. The most inclusive concepts are "atmosphere," "lithosphere," "hydrosphere," "biosphere," and "Solar System." Please keep in mind that which words belong to which categories depends on you. There are no absolute correct categorizations.
6. Now, arrange the primary concept, Earth, and the most inclusive concepts as they are arranged below. You can drag concept icons.



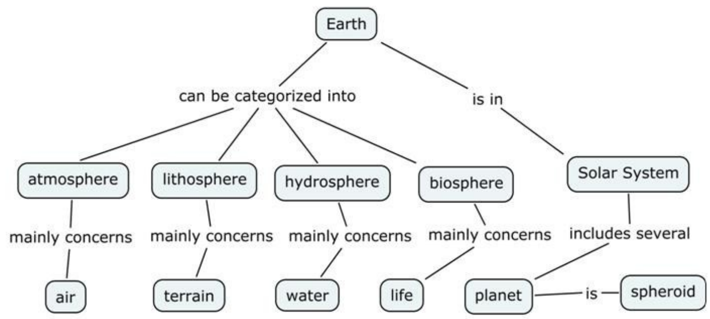
7. Next, you connect between the primary concept and the most inclusive concepts with a linking words or phrases. When you make a proposition by drawing an arrow on the map, try to choose good a linking word or phrase. Please keep in mind that what you describe linking words and phrases depends on you. There are no absolute correct words and phrases.
8. Now, connect each concept with lines and linking phrases as the map is shown below. When you click a concept icon, two arrows are shown. You can drag either of the arrows to a targeted concept icon. The two concept icons will get connected, and then a box including "????" will appear at the middle of the line. You can put a linking word and phrase in the box.



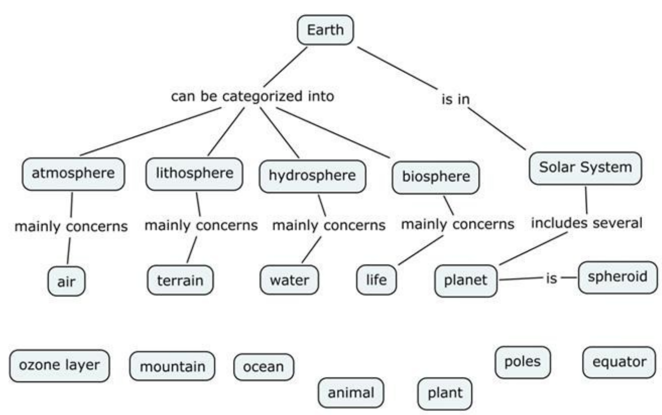
9. Next, you put the concepts that belong to an intermediate category below the higher order hierarchy. The corresponding concepts are "air," "terrain," "water," "life," "planet," and "spheroid." Please keep in mind that which words belong to which categories depends on you. There are no absolute correct categorizations.
10. Now, put the intermediate concepts as the map is shown below.



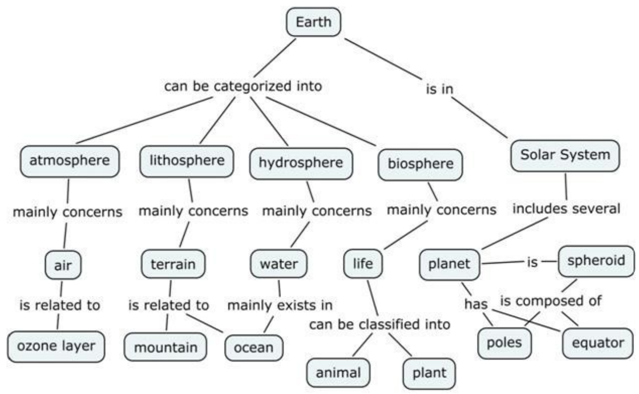
11. As you connected between the primary concept and the most inclusive concepts, you connect between the most inclusive concepts and the intermediate concepts with linking words and phrases.
12. Now, connect each concept with lines and linking phrases as the map is shown below.



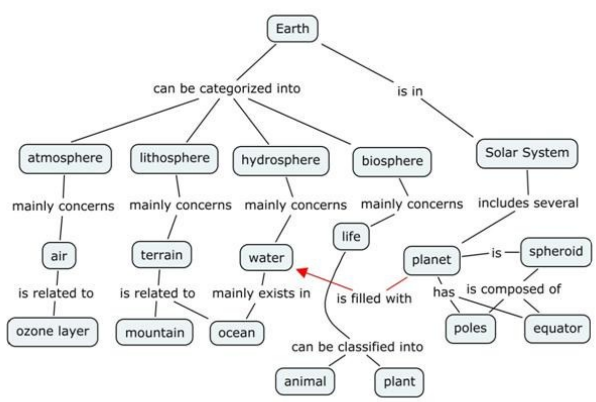
13. As you put the concepts that belong to the intermediate category below the higher-order hierarchy, you put the concepts that belong to the least inclusive category below the intermediate-order hierarchy. The corresponding concepts are “ozone layer,” “mountain,” “ocean,” “animal,” “plant,” “poles,” and “equator.”
14. Now, put the least inclusive concepts as the map is shown below.



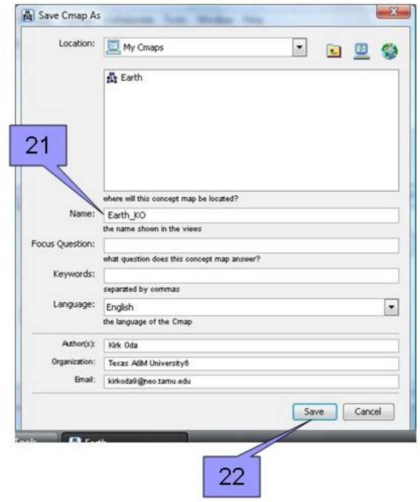
15. As you connected between the most inclusive concepts and the intermediate concepts, you connect between the intermediate concepts and the least inclusive concepts with linking words and phrases.
16. Now, connect each concept with lines and linking phrases as the map is shown below.



17. Next, a cross link is introduced. Cross links connect between concepts in one section of the map and concepts in another part of the concept "tree."
18. Look at the map shown below. The red arrow is the cross link that connects between "planet" under a higher-order concept and "water" under the other higher-order concept.
19. Put the cross link on your map.



20. Save your first concept map. On the main menu of Earth concept map window, click File → Save Cmap As.
21. The "Save Cmap As" window pops up. Name the file "Earth_*your initial*." For Example, my file name is Earth_ KO because my initial is KO.
22. Click the Save button. Your file was saved in the MyCmap folder on your desktop. You can close the Earth concept map window.
23. You have done with the first concept map. Keep in mind that there are no absolute correct and incorrect concept maps. There will not always be agreement among the people who draw concept maps. In addition, the structure of the concept map is hierarchical.



Now you make a concept map about "water" by yourself.

1. Start "CmapTools," if you have not opened it.
2. Drag the icon of "Water.cmap" into the CmapTools window. The Edit Resource Properties window pops up. Click the OK button.
3. Double-click the icon of "Water" in the Views –CmapTools window.
4. The Water concept map window pops up. The window has assigned words: water, chemical substance, life, liquid, solid, gaseous, water vapor, clouds, seawater, icebergs, ocean, river, two hydrogen atoms, a single oxygen atom, agriculture, irrigation, drinking water, and dehydration.
5. If you would like to make your own concept, use a "????" box. Click the box, and then change the word.
6. Please keep in mind that you do not have to use the concepts you do not know. In addition, you could use up to five your own words as a concept on your map.

Construct Concept Map about Water

The procedure:

1. Classify the concepts into three categories based on the most, intermediate and least inclusive concepts. You do not have to classify the concepts you do not know can add your familiar concepts up to five words. You could write down your classified words on a separated scratch paper.
2. On your map you put a primary concept, water, and the concepts that belong to the most inclusive category and then connect them with linking words or phrases.
3. You put the concepts that belong to intermediate category below the higher-order hierarchy and connect between the most inclusive and intermediate concepts with linking words or phrases.
4. As you created an Earth concept map, you put and connect between the intermediate and least inclusive concepts.
5. Think of cross links. If you have any ideas about the insertion of cross links, put them into your map.
6. Look at your completed concept map. If you think there are some parts to be revised, you could revise your map.

Save your Water concept map and turn it in to the experimenter.

- Save your water concept map. Name the file "Water_*your initial.*" For Example, my file name is Water_ KO because my initial is KO. Your new file will be saved in the MyCmap folder on your desktop.
- You need to turn in your water concept map to receive monetary compensation from the experimenter (Kirk Oda). You are asked to send your file (e.g., Water_KO.cmap) by email. You do not have to send your Earth concept map file. If you have not appointed for the first experiment session yet, you could tell your convenient time on the email. The experiment session takes place at Experimenter's office.

APPENDIX E

QUESTIONNAIRE OF PARTICIPANT PERSONAL INFORMATION

1. Name:

2. Gender: ☐ M / ☐ F

3. Age:

4. ☐ Freshman / ☐ Sophomore / ☐ Junior 3 / ☐ Senior / ☐ Graduate

5. Major: geography, meteorology

6. Have you ever taken a course related to spatial science? : ☐ Yes / ☐ No
   a. If you "Yes", which course?
   ☐ FRSC 398 - INTERP OF AERIAL PHOTO
   ☐ FRSC 461 - GEOG INFO SYS RES MGMT
   ☐ FRSC 462 - ADV GIS FOR RES MGMT
   ☐ GEOG 332 - THEMATIC CARTOGRAPHY
   ☐ GEOG 361 - REMOTE SENSING GEOS
   ☐ GEOG 390 - PRIN OF GIS
   ☐ GEOG 404 - SPATIAL THINKING
   ☐ GEOG 475 - ADVANCED GIS
   ☐ RENR 405 - GIS ENV PROBLEM SOLVING
   ☐ RENR 444 - REMOTE SENSING IN RENR
   ☐ Others ( )

7. How long have you used GIS software in a week this semester?
   ☐ Less then one hour
   ☐ More than one hour and less than two hours
   ☐ More than two hours and less than three hours
   ☐ More than three hours and less than five hours
   ☐ More than five hours and less than eight hours
   ☐ More than eight hours

8. When did you start using a map?
   ☐ I didn't start using a map until I became a college student.
   ☐ I start using a map when I was a high-school student.
   ☐ I start using a map when I was a junior high-school student.
   ☐ I start using a map when I was an elementary student.

9. How often do you use a map?
   ☐ About once a week
   ☐ About once a month
   ☐ About once a half year
   ☐ About once a year
   ☐ Never

10. Why did you decide to take GEOG 390?
   ☐ My advisor or a professor recommended taking this course.
   ☐ I didn't have any other courses to register.
   ☐ I think the knowledge and skills obtained in this course are marketable.
   ☐ This course fits my interest.

☐ My friend, boyfriend, or girlfriend takes this course.
☐ Others (GIS minor)

VITA

Katsuhiko Oda
Department of Geography
810 O&M Building
Texas A&M University
College Station, TX, 77843-3147
fromkirk@gmail.com

EDUCATION

Ph.D., Geography, Texas A&M University May 2011
Concentrations: GIS Education, Behavioral Geography, GIS Analysis for Urban Issues

M.A., Geography, The University of Toledo, Ohio Dec 1998
Concentrations: GIS, Cartography, Spatial Cognition

B.A., Geography, Nara University, Japan Mar 1994
Concentrations: GIS, Cartography

TEACHING EXPERIENCE

Teaching Assistant, Dept. of Geography, Texas A&M University Sep 2007- May 2009
Taught all GIS labs for Fall 2008 and Spring 2009 cartography and introductory-level GIS courses
Taught all labs for Fall 2007 and Spring 2008 physical geography courses

PROFESSIONAL EXPERIENCE

Research Assistant, Dept. of Architecture, Texas A&M University Sep 2009- May 2011
Conducted crime spatial analysis along estimated students' home-to-school routes
Developed GIS datasets to support a research project that studies elementary-school children's active school transportation such as walking and biking

GIS Student Technician, Dept. of Architecture, Texas A&M University Summer 2009
Geocoded elementary school students' addresses obtained from a survey in Austin

GIS Analyst, Tokyo Cartographic Co. Ltd., 2000-2004
Produced spatial data of street, lake, river, soil using ArcGIS
Wrote two reports regarding Lake Kasumigaura using ArcGIS and ArcHydro
Conducted research on manufacture of urban solid models using ArcGIS 3D Analyst and a rapid prototyping system

GIS Technician, Ecological Research Center of Kyoto University, 1999-2000
Structured GIS database of Lake Biwa using Arc/Info

Map Editor, Hyogen Kenkyujo Co. Ltd., 1994-1996